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ASSESSMENT OF THE IMPACT OF RESOURCE RECOVERY ON THE ENVIRONMENT

by

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FOREWORD

The Environmental Protection Agency was created because of increasing public and government concern about the dangers of pollution to the health and welfare of the American people. Noxious air, foul water, and spoiled land are tragic testimony to the deterioration of our natural environment. The complexity of that environment and the interplay between its components require a concentrated and integrated attack on the problem.

Research and development is that necessary first step in problem solution and it involves defining the problem, measuring its impact, and searching for solutions. The Municipal Environmental Research Laboratory develops new and improved technology and systems for the prevention, treatment, and management of wastewater and solid and hazardous waste pollutant discharges from municipal and community sources, for the preservation and treatment of public drinking water supplies, and to minimize the adverse economic, social, health, and aesthetic effects of pollution. This publication is one of the products of that research; a most vital communications link between the researcher and the user community.

One of the objectives of the Resource Conservation and Recovery Act of 1976 is to promote the protection of health and the environment through resource recovery. It was not known, however, to what extent such a policy would abate the pollution caused by the disposal of solid wastes. This report addresses the issue by first quantifying the present environmental effects of the disposal of municipal solid wastes, and then comparing these effects to those that would be expected under an assumed scenario of resource recovery sometime in the future. The results are of value not only in placing resource recovery into a national perspective, but for the planning of research and development programs as well.

Francis T. Mayo, Director
Municipal Environmental Research
Laboratory

ABSTRACT

This assessment of the environmental impact of resource recovery examines the environmental effects that will derive from municipal solid waste disposal in 1990 and the changes in these effects that will result from implementation of resource recovery from municipal solid waste. The environmental effects considered in this study are the direct effects of municipal solid waste disposal as well as the secondary effects of substituting materials recovered from municipal solid waste for virgin materials in the production of steel, aluminum, glass, and energy. The energy aspects of resource recovery--that is, energy conservation resulting from use of recovered scrap in materials production and energy production by recovery of energy from municipal solid waste--are also evaluated. The analysis is based on specific scenarios for municipal solid waste disposal in 1990 without and with implementation of resource recovery.

The net environmental impact of resource recovery from municipal solid waste will be primarily beneficial. Emissions of most air pollutants will be reduced. The discharge of pollutants to surface waters will increase. The quantities of all pollutants present in leachate from landfilled municipal solid waste and resource recovery residue will decrease. Less landfill capacity will be required for disposal of municipal solid waste. Energy savings will be realized from energy conservation in materials production and energy recovery from municipal solid waste.

This report was submitted in fulfillment of Contract No. 68-03-2596 by The MITRE Corporation, Metrek Division, under the sponsorship of the United States Environmental Protection Agency. This report covers the period from September 26, 1977 to September 21, 1978, and work was completed on November 30, 1978.

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SECTION 1

SUMMARY

This study was prepared for the Processing Branch in the Solid and Hazardous Waste Research Division of the Municipal Environmental Research Laboratory of the United States Environmental Protection Agency (EPA). The objectives were to determine quantitatively the effects on the environment of municipal solid waste disposal and of resource recovery from the municipal solid waste, as well as the potential benefits of resource recovery in mitigating the environmental effects of municipal solid waste disposal. The data are presented in tabular form for use in EPA program planning.

In this assessment of the environmental impact of resource recovery from municipal solid waste, two scenarios are presented for municipal solid waste disposal in 1990--one without and the other with implementation of resource recovery. The differences between the environmental effects that would result from the two scenarios constitute the environmental impact of resource recovery. Municipal solid waste, as considered in this study, is comprised of residential and commercial wastes. It is projected that approximately 197,000,000 tons of municipal solid waste will be generated in the United States in 1990.

Under the scenario for municipal solid waste disposal in 1990 without resource recovery, five percent (10,000,000 tons) will be incinerated and the remaining 95 percent (187,000,000 tons) will be landfilled. The scenario for municipal solid waste disposal with implementation of resource recovery stipulates that five percent (10,000,000 tons) will be incinerated, 80 percent (157,000,000 tons) will be landfilled, and 15 percent (30,000,000 tons) will be processed for resource recovery. With resource recovery, ferrous metals, aluminum, and glass will be recovered from the 15-percent portion of the municipal solid waste and the recovered materials will replace virgin materials in the production of steel, aluminum, and glass. In addition, energy will be derived from the same portion of the municipal solid waste by mass burning in waterwall incinerators and by cofiring of refuse-derived fuel with coal; this energy will replace a similar amount that would otherwise be generated by coal combustion.

The environmental effects of resource recovery from municipal solid waste are primarily favorable. (See Table XXI for a summary of the effects.) Net emissions of all but three of the air pollutants considered will be reduced. Emissions of carbon monoxide will be reduced in 1990 by about 2,300,000 tons and emissions of carbon dioxide, NO_x, and methane by about 310,000 tons, 150,000 tons, and 114,000 tons, respectively. Smaller reductions will occur in emissions of SO_x (~23,000 tons) and hydrocarbons (~7200 tons). There

will be slight increases in the quantities of total particulates (~1000 tons) and aldehydes (~2500 tons) emitted and a larger increase (~140,000 tons) in chloride emissions.

The quantities of pollutants that will be discharged to surface waters in incinerator wastewater effluent will increase because more municipal solid waste will undergo mass burning with implementation of the scenario for resource recovery. With resource recovery from municipal solid waste, smaller quantities of pollutants will be present in landfill leachate. The decrease will range from 3 tons of cadmium, a minimum of 25 tons of sulfate and about 100 tons of chromium, copper, lead, and nickel to more than 1,000,000 tons of magnesium. In the absence of data on leachate contributions to the pollutant loadings of ground and surface waters, the net effects of resource recovery on the water resources cannot be determined.

The requirement for landfill capacity to dispose of municipal solid waste and the residues from mass burning and resource recovery will be decreased by about 44,260 acre-feet under the scenario for resource recovery. The landfill capacity needed with resource recovery from municipal solid waste will be about 85 percent of the capacity that would be required if there were no resource recovery.

Energy derived from municipal solid waste in 1990 will amount to 161.4×10^{12} Btu (28.8×10^{6} barrels of crude oil equivalent). Energy conservation that would accrue from substitution of recovered for virgin materials in the production of steel, aluminum, and glass

will be about 75.2 x 10^{12} Btu (13.4 x 10^{6} BCOE). The total energy savings that can be realized from resource recovery from municipal solid waste will therefore be about 236.6 x 10^{12} Btu or 42.3 x 10^{6} barrels of crude oil equivalent.

SECTION 2

INTRODUCTION

A study was made of the environmental impact of resource recovery from municipal solid waste. For the purposes of this study, municipal solid waste is defined as being comprised of residential and commercial solid waste, i.e., the urban refuse that is normally handled by municipalities.

Resource recovery consists of the recovery of scrap ferrous metals, aluminum, and glass from municipal solid waste and their substitution for virgin materials in production of steel, aluminum products, and glass containers. Resource recovery also includes recovery of the energy content of the municipal solid waste.

The year 1990 was selected as the base year for the study because it is the earliest date by which a reasonable number of resource recovery facilities would be fully operational and, therefore, resource recovery would be having a significant impact on the environment. Two scenarios are proposed for municipal solid waste disposal in 1990 -- one without and the other with resource recovery. Some reference is also made to the present, specifically 1975.

Pollutants emitted/discharged to the air, surface water, and landfill leachate as a consequence of municipal solid waste disposal

constitute the direct environmental effects of municipal solid waste. The differences in quantities of these pollutants that would result from implementation of the two scenarios comprise the direct effects of resource recovery. Similarly, the secondary effects of resource recovery are the differences in environmental effects that would result from substitution of recovered materials for virgin materials as well as the energy conservation/production aspects of resource recovery.

SECTION 3

FINDINGS

The findings of the study are presented in the following 21 tables. For a listing of the tables, see pp. vi and vii.

The methods of calculation are presented in Appendix A. The sections and equations in this appendix are keyed by number to the tables in the text.

DISCUSSION: TABLE I

The exact quantity of municipal solid waste that is generated in the United States is unknown. Estimations were therefore made for 1975 and 1990 (Table I) based on (a) a rate of municipal solid waste generation that is expressed in terms of pounds per person daily and (b) the 1975 and 1990 populations as estimated and projected by the United States Census Bureau. It was assumed that:

- The rate of generation of municipal solid waste (residential and commercial refuse) is dependent on community size, i.e., on the degree of commercial development, with a saturation limit of 5.5 pounds per person daily.
- The rate of municipal solid waste generation is independent of time, i.e., the rate will be the same in 1990 as in 1975.
- The distribution of population is independent of time, i.e., the percentages of population by community size as reported in the 1970 Census of Population (1) will remain constant through 1990.
- The rate of population growth will be in accordance with the Series II projections of the United States Census Bureau, i.e., 2.1 lifetime births per woman (vs. 1.7 and 2.7 for Series I and III, respectively).

By this method, it is estimated that about 173 million tons of municipal solid waste were generated in the United States in 1975. It has been reported (2) that estimates of municipal solid waste quantities are accurate within ±25 percent; the range of 173 million tons ±25 percent does encompass the 136 million tons estimated for 1975 that is given in the Fourth Report

DISCUSSION: TABLE I (Concluded)

Report to Congress (5). This figure also approximates the estimate of 160 million tons for 1976 cited by another EPA source (6).

The estimate that 197 million tons of municipal solid waste will be generated in the United States in 1990 is similar to the EPA projection of 225 million tons (5).

TABLE I

GENERATION OF MUNICIPAL SOLID WASTE (MSW) IN THE UNITED STATES[a]

PLACES/URBANIZED AREAS[b]				1975		1990	
POPULATION SIZE	RATE OF MSW GENERATION[c] (ppd)	POPULATION[d] (%)	NUMBER OF URBANIZED AREAS[e]	POPULATION (10^6)	MSW GENERATED (10^6 tons/yr)	POPULATION (10^6)	MSW GENERATED (10^6 tons/yr)
<1,000	2.0	23	0	49.1	17.9	56.0	20.4
1,000-10,000	4.0	10	0	21.4	15.6	24.4	17.8
10,000-100,000	4.5	11	0	23.5	19.3	26.8	22.0
100,000-500,000	5.5	14	126	29.9	30.0	34.1	34.2
500,000-1,000,000	5.5	7	21	14.9	15.0	17.0	17.1
>1,000,000	5.5	35	25	74.7	75.0	85.2	85.5
Total				213.5[f]	172.8	243.5[g]	197.0

[a] Municipal solid waste consists of residential and commercial wastes.

[b] An urbanized area consists of a central city, or cities, and surrounding closely settled territory (Reference 1).

[c] Reference 2.

[d] Percentage of total population residing in each size place or urbanized area; based on 1970 census (Reference 3).

[e] Reference 3.

[f] United States Census Bureau estimate (Reference 4).

[g] United States Census Bureau projection for Series II rate of growth (Reference 4).

DISCUSSION: TABLE II

This study is based on the scenarios presented in Table II. It is projected that in 1990 30 million tons of municipal solid waste will be processed for resource recovery -- one-half by front-end processing with materials separation and combustion of RDF and one-half by mass burning of raw refuse with energy recovery and with materials recovery from the residue.

Thirty million tons corresponds to the annual capacity of 50 large scale resource recovery facilities, each processing 2000 tons per day. As of September 1977, there were 25 projects with a total capacity of 24,000 tons per day in funded design, construction, or operation in the United States (7).

TABLE II

SUMMARY OF SCENARIOS: HANDLING OF MUNICIPAL SOLID WASTE

DISPOSAL METHOD/ PROCESS	1975		1990			
			WITHOUT RESOURCE RECOVERY		WITH RESOURCE RECOVERY	
	%	10^6 tons	%	10^6 tons	%	10^6 tons
Mass Burning	10	17.3	5	10	5	10
Landfill	90	155.5	95	187	80	157
Resource Recovery						
Front-End Processing with Materials Separation and Combustion of RDF					7.5	15
Mass Burning of Raw Refuse with Energy Recovery (Waterwall Incineration) and Materials Recovery from Residue					7.5	15
TOTAL		172.8		197		197

DISCUSSION: TABLE III

The composition of municipal solid waste varies with -- among other factors -- season of the year, geographic location, population characteristics, and degree of urbanization (Table III). A "typical" composition was selected as being representative of municipal solid waste.

Changes in composition are determined by such factors as technological developments (e.g., fuel types, packaging materials) and economic considerations (e.g., the relative costs of petroleum-based products). Because of the numerous variables, prediction of composition at a specific future date is difficult and unreliable. It is therefore assumed that the typical composition of municipal solid waste in 1990 will be the same as that in 1975.

TABLE III

COMPOSITION OF MUNICIPAL SOLID WASTE

MATERIAL	CONTENT (wt %)			
	REPORTED[a]			TYPICAL[b]
	I	II	III	
Food wastes	17	17	15	17
Garden trimmings	8	19	12	10
Paper products	44	32	44	40
Plastics, rubber, and leather	3	6	4	6
Textiles	2	2	2	2
Wood	3	4	2	4
Metals	9	9	9	10[c]
Glass and ceramics	9	10	8	10
Ash, rock, and dirt	5	1	4	1

[a]I: Average for 30 United States cities and areas (1965-1970) (Reference 2).
II: Data for 1975; adapted from Reference 5.
III: Data for 1975 (Reference 8, p. 55).
[b]Reference 9.
[c]Metals: 9% ferrous, 1% nonferrous.

DISCUSSION: TABLE IV

The major pollutants that derive from disposal/processing of municipal solid waste are listed in Table IV.

TABLE IV

MAJOR POLLUTANTS FROM DISPOSAL OF MUNICIPAL SOLID WASTE

PROCEDURE	RECEIVING MEDIUM	
	AIR	WATER
Mass Burning	particulates (metals) SO_x NO_x hydrocarbons viruses & bacteria volatile metals volatile organic compounds	metals Cl^-, PO_4^{-3}, SO_4^{-2} phenols
Landfill	CO_2 CH_4 H_2S	organic compounds metal cations Cl^-, SO_4^{-2}
Resource Recovery		
Front-End Processing		
Materials Separation	volatile organic compounds viruses & bacteria dust	
Energy Recovery from RDF	particulates SO_x NO_x hydrocarbons viruses & bacteria volatile organic compounds	Cl^-, PO_4^{-3}, SO_4^{-2} phenols
Mass Burning with Resource Recovery		
Inceration with Energy Recovery	see Mass Burning above	see Mass Burning above
Materials Recovery	dust	

DISCUSSION: TABLE V

Reported concentrations of pollutants that result from municipal solid waste disposal are listed in Table V. The air and surface water pollutants from mass burning enter the environment via stack emissions and incinerator wastewater, respectively. Pollutants from landfills leach into the groundwater; some gases are generated also.

It is assumed that the reported concentrations and emission factors reflect only the pollutants that are derived from municipal solid waste. It is known that there is an industrial component in the waste stream, but the industrial contribution to total concentrations and quantities of pollutants is not considered in this study.

TABLE V

REPORTED CONCENTRATIONS OF POLLUTANTS FROM MUNICIPAL SOLID WASTE DISPOSAL

RECEIVING MEDIUM/POLLUTANT	SOURCE								
	MASS BURNING						LANDFILL		
	STACK EMISSIONS (lb/ton)		WASTEWATER (ppm)				LEACHATE[g] (ppm)		GASES[h] (cu ft/ton in 25 yrs)
			UNCONTROLLED			CONTROLLED [d,f]			
	UNCONTROLLED [a]	CONTROLLED [b] (% REDUCTION)	QUENCH WATER [c,d]	SCRUBBER WATER	FINAL EFFLUENT [d,e]		I	II	
AIR									
Particulates	30	96[a]							
SO_x (as SO_2)	2.5	29[j]							
NO_x (as NO_2)	3	NA							
CO	35	NA							
Hydrocarbons (as CH_4)	1.5	NA							
Aldehydes	NA[i]	30[j]							
Chlorides (as HCl)	NA	94[j]							
CO_2	NA	NA							4560
CH_4									4560
SURFACE WATER									
Aluminum			NA	20.4[d,k]	NA				
Barium			NA	5.0[d,k]	NA				
Calcium			42	NA	NA				
Chloride			78	180 - 3540[k,l]	30 - 193				
Chromium			NA	0.13[d,k]	NA	1.0			
Copper			NA	0.02[d,k]	NA	0.05			
Cyanide			NA	4.98[d,k]	NA	0			
Iron			1.40	1.30[d,k]	NA	0.3			
Lead			0.3	1.30[d,k]	NA	0.5			
Magnesium			0	NA	NA				
Manganese			NA	0.30[d,k]	NA				
Phenols			NA	1.72[d,k]	NA	0.005			
Phosphate			0.88	3 - 90[k]	2 - 9				
Sulfate			63	19[l] - 1830[k]	32 - 50				
Zinc			1.27	2.4[d,k]	NA	1.0			

TABLE V (Concluded)

REPORTED CONCENTRATIONS OF POLLUTANTS FROM MUNICIPAL SOLID WASTE DISPOSAL

RECEIVING MEDIUM/POLLUTANT	SOURCE								
	MASS BURNING						LANDFILL		
	STACK EMISSIONS (lb/ton)		WASTEWATER				LEACHATE[g] (ppm)		GASES[h] (cu ft/ton in 25 yrs)
			UNCONTROLLED			CONTROLLED[d,f]			
	UNCONTROLLED[a]	CONTROLLED[b] (% REDUCTION)	QUENCH WATER[c,d]	SCRUBBER WATER	FINAL EFFLUENT[d,e]		I	II	
LEACHATE[g]									
Cadmium							0.03 - 17[m]	0.03	
Calcium							60 - 7200[n]	NA	
Chloride							5 - 2467[n]	NA	
Chromium							NA	1.05	
Copper							<0.2 - 9.9[m,n]	1.30	
Iron, total							0.5 - 2820[n]	810	
Lead							0.1 - 2[m]	1.4	
Magnesium							17 - 15,600[n]	NA	
Manganese							0.06 - 125[n]	NA	
Nickel							NA	1.20	
Potassium							29 - 3770[n]	NA	
Sodium							34 - 7700[n]	NA	
Sulfate							1 - 3770[m,n]	NA	
Zinc							0.05 - 370[m,n]	155	

[a] Reference 10.

[b] Control: electrostatic precipitator.

[c] Data for Braintree, Massachusetts incinerator (Reference 11). Concentrations were greater in quench waters of other incinerators (References 12, 13, 14).

[d] Average absolute concentration, i.e., with concentration in tap/raw water subtracted.

[e] Includes wastewater from residue quenching, wet scrubber, and residue and fly ash conveying. Ranges of concentrations as reported in Reference 13. Average concentrations reported in Reference 14 were greater.

[f] State of Florida quality standard for incinerator effluents (Reference 14).

[g] Concentrations in leachate; these are not concentrations in groundwater. I: Ranges of values reported for lysimeter and field tests of leachate from municipal solid waste (References 15 and 16). II: Data for leachate from a well designed landfill (Reference 17).

[h] Maximum generation under proper moisture conditions (Reference 2).

[i] NA: Data not available.

[j] Reference 18.

[k] Reference 14.

[l] Reference 13.

[m] Reference 15.

[n] Reference 16.

DISCUSSION: TABLE VI

The estimated quantities of pollutants that entered the environment in 1975* as the result of municipal solid waste disposal in 1975 are given in Table VI. Pollutant masses were calculated on the basis of the 1975 disposal scenario (Table II), the reported pollutant concentrations and emission factors (Table V), and the EPA estimate of landfill leachate volume (Reference 19). Therefore, the calculations were based on the following assumptions:

- In 1975, 17.3 million tons of municipal solid waste were disposed of by mass burning and 155.5 million tons were landfilled.
- The pollutant concentrations and emission factors listed in Table V are representative for pollutants from municipal solid waste.
- Emissions and discharges of pollutants were not controlled.
- In 1975 there were 18,500 landfills and dumps. Landfill area comprised approximately 500,000 acres, and leachate from landfills amounted to 90 billion gallons (Reference 19).
- The water requirement for residue quenching and fly ash conveying was six tons of water per ton of incinerated municipal solid waste (Reference 14), and wastewater was discharged to surface water without recycling.
- Conditions were suitable for maximum generation of gas from landfilled refuse, and the rate of gas generation is uniform over 25 years.

*Quantities of pollutants in landfill gases are the estimated quantities produced in 1976 from the municipal solid waste that was landfilled in 1975.

TABLE VI

ESTIMATED QUANTITIES OF POLLUTANTS FROM DISPOSAL OF MUNICIPAL SOLID WASTE IN 1975 (in tons)

RECEIVING MEDIUM/ POLLUTANT	DISPOSAL METHOD[a]		TOTAL
	MASS BURNING[b]	LANDFILL	
AIR			
Particulates	260,000		260,000
SO_x (as SO_2)	22,000		22,000
NO_x (as NO_2)	26,000		26,000
CO	303,000		303,000
Hydrocarbons (as CH_4)	13,000		13,000
Aldehydes	NA[c]		NA
Chlorides (as HCl)	NA		NA
CO_2	NA	1,620,000[d]	1,620,000[d]
CH_4		589,000[d]	589,000[d]

TABLE VI (Continued)

ESTIMATED QUANTITIES OF POLLUTANTS FROM DISPOSAL OF MUNICIPAL SOLID WASTE IN 1975 (in tons)

RECEIVING MEDIUM/ POLLUTANT	DISPOSAL METHOD[a]		TOTAL
	MASS BURNING[b]	LANDFILL	
SURFACE WATER			
Aluminum	NA		NA
Barium	NA		NA
Calcium	4360		4360
Chloride	8100		8100
Chromium	NA		NA
Copper	NA		NA
Cyanide	NA		NA
Iron	145		145
Lead	31		31
Magnesium	0		0
Manganese	NA		NA
Phenols	NA		NA
Phosphate	91		91
Sulfate	6540		6540
Zinc	132		132

TABLE VI (Continued)

ESTIMATED QUANTITIES OF POLLUTANTS FROM DISPOSAL OF MUNICIPAL SOLID WASTE IN 1975 (in tons)

RECEIVING MEDIUM/ POLLUTANT	DISPOSAL METHOD[a]			TOTAL
	MASS BURNING[b]	LANDFILL[c]		
		I	II	
LEACHATE				
Cadmium		11 - 6385	13	13
Calcium		22,550 - 2,705,000	NA	22,550 - 2,705,000
Chloride		1880 - 926,500	NA	1880 - 926,500
Chromium		NA	463	463
Copper		<75 - 3720	573	573
Iron, total		188 - 1,060,000	357,000	357,000
Lead		38 - 751	617	617
Magnesium		6385 - 5,860,000	NA	6385 - 5,860,000
Manganese		23 - 46,950	NA	23 - 46,950
Nickel		NA	529	529
Potassium		10,900 - 1,415,000	NA	10,900 - 1,415,000

TABLE VI (Concluded)

ESTIMATED QUANTITIES OF POLLUTANTS FROM DISPOSAL OF MUNICIPAL SOLID WASTE IN 1975 (in tons)

RECEIVING MEDIUM/ POLLUTANT	DISPOSAL METHOD[a]			TOTAL
	MASS BURNING[b]	LANDFILL[e]		
		I	II	
LEACHATE				
Sodium		12,750 - 2,890,000	NA	12,750 - 2,890,000
Sulfate		376 - 1,415,000	NA	376 - 1,415,000
Zinc		19 - 139,000	68,300	68,300

[a]Of the municipal solid waste, 10 percent was disposed of by mass burning, 90 percent by landfill (see Table II).

[b]Quantities of pollutants if all incinerator emissions were uncontrolled.

[c]NA: Data not available.

[d]Gases generated nationally in 1976 by municipal solid waste landfilled in 1975.

[e] I: National estimates based on reported ranges of concentrations.
II: National estimates based on extrapolation of data for a single well designed landfill; probably approximates the national average.

DISCUSSION: TABLE VII

The concentrations of pollutants that will be emitted/discharged into the environment in 1990 as the result of municipal solid waste (MSW) disposal are listed in Table VII. Sources of pollutants will be mass burning of raw refuse (without and with energy recovery), landfilling of MSW, energy recovery from refuse-derived fuel (RDF), and landfilling of residue from resource recovery.

Selection of pollutant concentrations for 1990 was based on the following assumptions:

- In 1990, only those municipal incinerators that came on line after 1970 will be in operation.
- Emissions from municipal incinerators in 1990 will be the same as those from the Harrisburg, PA incinerator (360 tons per day, travelling grate, Martin process) as monitored in 1975. Energy recovery will not affect emissions.
- Pollutant concentrations in wastewater from municipal incinerators in 1990 will be the same as those listed for 1975 (Table V) except for those pollutants which are subject to effluent limitations for incinerator wastewater, as set by the State of Florida.
- Emissions from cofiring coal and RDF in 1990 will be the same as those from the Ames, IA power plant (coal-RDF at 80:20, 80 percent load, stoker boiler #5, 7.5 MW) as monitored in 1977 except for particulate emissions which will be in compliance with 1978 New Source Performance Standards for Coal-Fired Power Plants.
- The differences in emissions from the same unit operating under similar conditions during coal combustion and during cofiring of coal and RDF constitute the emissions that are attributable to the RDF fraction.

DISCUSSION: TABLE VII (Concluded)

- In 1990, the pollutants in wastewater from cofiring of coal and RDF that derive from the RDF fraction will be the same as those in municipal incinerator wastewater except for the absence of compounds of metals removed during preparation of RDF.

- The concentration ranges for leachate from landfilled MSW will be the same in 1990 as those reported in 1975 inasmuch as the latter probably reflect the ranges of concentrations in leachate from old as well as new landfills.

- The compositions of the residues from resource recovery that are disposed of in landfills will differ from the composition of MSW that is landfilled directly, and therefore the characteristics of the leachates that are derived from these materials will also differ.

- Equilibrium modeling of leachate from landfilled resource recovery residue provides an approximation of leachate quality. See Appendix B for discussion.

TABLE VII

PROJECTED CONCENTRATIONS OF POLLUTANTS FROM MUNICIPAL SOLID WASTE (MSW) DISPOSAL IN 1990

RECEIVING MEDIUM/POLLUTANT	SOURCE								
	MASS BURNING		LANDFILL OF MSW			ENERGY RECOVERY FROM RDF		LANDFILL OF RESIDUE FROM RESOURCE RECOVERY	
	STACK EMISSIONS (lb/ton)	WASTE - WATER (ppm)	LEACHATE[a] (ppm) I	LEACHATE[a] (ppm) II	GASES[b] cu ft/ton in 25 yrs	STACK EMISSIONS[c] (lb/ton RDF)	WASTE - WATER[d] (ppm)	LEACHATE[e] (ppm)	GASES (cu ft/ton)
AIR									
Particulates	1.02[f]					1.28[f]			
SO_x (as SO_2)	2.02[f,g]					4.43			
NO^x	1.14 - 3.43[f]					1.54			
CO^x	0.69 - 2.07[f]					NA			
Hydrocarbons (as CH_4)	0.2[h]					0.0036			
Aldehydes (as Formaldehyde)	0.0004 - 0.01[h]					-0.36			
Chlorides (as HCl)	3.71 - 7.41[f]					7.81			
CO_2	NA				4560	NA			0
CH_4					4560				0
SURFACE WATER									
Aluminum		20.4[j]					~0		
Barium		5.0[j]					5.0		
Calcium		42[k]					42		
Chloride		30 - 193[l]					30 - 193		
Chromium		0.13[j,m]					0.13		
Copper		0.02[j,n]					~0		
Cyanide		0[o]					0		
Iron		0.3[o]					~0		
Lead		0.5[o]					~0		
Magnesium		0[k]					0		
Manganese		0.30[j]					~0		
Phenols		0.005[o]					0.005		
Phosphate		2 - 9[l]					2 - 9		
Sulfate		32 - 50[l]					32 - 50		
Zinc		1.0[l]					~0		

TABLE VII (Concluded)

PROJECTED CONCENTRATIONS OF POLLUTANTS FROM MUNICIPAL SOLID WASTE (MSW) DISPOSAL IN 1990

RECEIVING MEDIUM/POLLUTANT	SOURCE								
	MASS BURNING		LANDFILL OF MSW			ENERGY RECOVERY FROM RDF		LANDFILL OF RESIDUE FROM RESOURCE RECOVERY	
	STACK EMISSIONS (lb/ton)	WASTE-WATER (ppm)	LEACHATE [a] (ppm) I	LEACHATE [a] (ppm) II	GASES[b] cu ft/ton in 25 yrs	STACK EMISSIONS [c] (lb/ton RDF)	WASTE-WATER[d] (ppm)	LEACHATE[e] (ppm)	GASES (cu ft/ton)
LEACHATE[a]									
Cadmium			0.03 - 17[p]	0.03				0.00578	
Calcium			60 - 7200[q]	NA				26.8	
Chloride			5 - 2467[q]	NA				NA	
Chromium			NA	1.05				NA	
Copper			<0.2 - 9.9[p,q]	1.30				1.26	
Iron, total			0.5 - 2820[q]	810				0.0138	
Lead			0.1 - 2[p]	1.4				0.00425	
Magnesium			17 - 15,600[q]	NA				13.2	
Manganese			0.06 - 125[q]	NA				2.08	
Nickel			NA	1.20				0.0220	
Potassium			29 - 3770[q]	NA				NA	
Sodium			34 - 7700[q]	NA				NA	
Sufate			1 - 3770[p,q]	NA				11.9	
Zinc			0.05 - 370[p,q]	155				0.138	

[a] I: Ranges of values reported for lysimeter and field tests of leachate from MSW; these are not the concentrations in groundwater.
II: Data for leachate from a well designed landfill (Reference 17).

[b] Maximum generation under proper moisture conditions (Reference 2).

[c] Portion of cofiring emissions that is attributable to the RDF fraction (see Assumptions). Based on 1977 data for Ames, Iowa power plant cofiring coal and RDF at 100:0 and at 80:20 (based on heat input to boiler)(References 20 and 21) and current (1978) New Source Performance Standards for Coal-Fired Power Plants (Reference 22). The heating value of the RDF was 12.82 million Btu/ton (Reference 21), which is about 10 percent higher than "usual," and emissions data were reported in terms of heat input (grams/megajoule).

[d] Based on pollutants from incinerator wastewater.

[e] Based on equilibrium composition of a hypothetical liquid-phase/solid-phase system.

[f] Data for Harrisburg, PA incinerator; emissions controlled by electrostatic precipitator (Reference 23).

[g] Sulfur content in MSW: 0.1%.

[h] Reference 24.

[i] NA: Data not available.

[j] Concentration in scrubber water (Reference 14).

[k] Concentration in quench water (Reference 11).

[l] Concentration in final effluent (Reference 13).

[m] Florida quality standard for incinerator effluent is 1.0 ppm (Reference 14).

[n] Florida quality standard for incinerator effluent is 0.05 ppm (Reference 14).

[o] Florida quality standard for incinerator effluent (Reference 14).

[p] Reference 15.

[q] Reference 16.

[r] Maximum emission factor for particulates if boiler is to be in compliance with the New Source Performance Standard for Coal-Fired Power Plants of 0.1 pound particulates/10^6 Btu (Reference 22). See Example 1 under Equation VII-3b in Appendix A.

DISCUSSION: TABLE VIII

The projected quantities of pollutants that will enter the environment in 1990* as the result of municipal solid waste disposal in 1990, if resource recovery is not implemented, are given in Table VIII. Pollutant masses were calculated on the basis of the 1990 disposal scenario without resource recovery (Table II), the pollutant concentrations and emission factors projected for 1990 (Table VII), and the projected volume of landfill leachate in 1990. Calculations were based on the following assumptions:

- In 1990, 10 million tons of municipal solid waste will be disposed of by mass burning and 187 million tons will be landfilled.
- The pollutant concentrations and emission factors listed in Table VII are representative for pollutants from municipal solid waste in 1990.
- The increase in landfill area (i.e., the area in 1990 relative to that in 1975) will be proportional to the increase in landfill capacity required for disposal of municipal solid waste and incinerator residue (Table XX).
- Municipal landfill area will be about 600,000 acres in 1990. (See Appendix A, Equation VIII-4b for calculation.)
- Leachate from municipal landfills will amount to 108 billion gallons in 1990. (See Appendix A, Equation VIII-4c for calculation.)

*Quantities of pollutants from landfill gases represent the projected quantities that will be produced in 1991 from the municipal solid waste that will be landfilled in 1990.

DISCUSSION: TABLE VIII (Concluded)

- The quantity of wastewater from mass burning of municipal solid waste in 1990 will be equivalent to the water requirement for residue quenching, fly ash conveying, and flue gas scrubbing -- i.e., three tons of water per ton of municipal solid waste with water recycling.

- Conditions will be suitable for maximum generation of gases from landfilled municipal solid waste, and the rate of gas generation will be uniform over 25 years.

TABLE VIII

PROJECTED QUANTITIES OF POLLUTANTS (in tons) FROM DISPOSAL OF MUNICIPAL SOLID WASTE IN 1990 WITHOUT IMPLEMENTATION OF RESOURCE RECOVERY

RECEIVING MEDIUM/ POLLUTANT	DISPOSAL METHOD[a]		TOTAL
	MASS BURNING	LANDFILL[b]	
AIR			
Particulates	5100		5100
SO_x (as SO_2)	10,100		10,100
NO_x (as NO_2)	5700 - 17,150		5700 - 17,150
CO	3450 - 10,350		3450 - 10,350
Hydrocarbons (as CH_4)	1000		1000
Aldehydes (as Formaldehyde)	2 - 50		2 - 50
Chlorides (as HCl)	18,550 - 37,050		18,550 - 37,050
CO_2	NA[c]	1,945,000[d]	1,945,000[d]
CH_4		708,000[d]	708,000[d]

TABLE VIII (Continued)

PROJECTED QUANTITIES OF POLLUTANTS (in tons) FROM DISPOSAL OF MUNICIPAL SOLID WASTE IN 1990 WITHOUT IMPLEMENTATION OF RESOURCE RECOVERY

RECEIVING MEDIUM/ POLLUTANT	DISPOSAL METHOD[a]		TOTAL
	MASS BURNING	LANDFILL[b]	
SURFACE WATER[e]			
Aluminum	612		612
Barium	150		150
Calcium	1260		1260
Chloride	900 - 5790		900 - 5790
Chromium	4		4
Copper	1		1
Cyanide	0		0
Iron	9		9
Lead	15		15
Magnesium	0		0
Manganese	9		9
Phenols	~0		~0
Phosphate	60 - 270		60 - 270
Sulfate	960 - 1500		960 - 1500
Zinc	30		30

TABLE VIII (Continued)

PROJECTED QUANTITIES OF POLLUTANTS (in tons) FROM DISPOSAL OF MUNICIPAL SOLID WASTE IN 1990 WITHOUT IMPLEMENTATION OF RESOURCE RECOVERY

RECEIVING MEDIUM/ POLLUTANT	DISPOSAL METHOD[a]			TOTAL
	MASS BURNING	LANDFILL[b]		
		I	II	
LEACHATE				
Cadmium		14 - 7660	16	16
Calcium		27,050 - 3,245,000	NA	27,050 - 3,245,000
Chloride		2255 - 1,110,000	NA	2255 - 1,110,000
Chromium		NA	555	555
Copper		<90 - 4460	688	688
Iron, total		225 - 1,270,000	428,500	428,500
Lead		45 - 901	741	741
Magnesium		7660 - 7,030,000	NA	7660 - 7,030,000
Manganese		27 - 56,350	NA	27 - 56,350
Nickel		NA	635	635
Potassium		13,050 - 1,700,000	NA	13,050 - 1,700,000

TABLE VIII (Concluded)

PROJECTED QUANTITIES OF POLLUTANTS (in tons) FROM DISPOSAL OF MUNICIPAL SOLID WASTE IN 1990 WITHOUT IMPLEMENTATION OF RESOURCE RECOVERY

RECEIVING MEDIUM/ POLLUTANT	DISPOSAL METHOD[a]			TOTAL
	MASS BURNING	LANDFILL[b]		
		I	II	
LEACHATE				
Sodium		15,300 - 3,470,000	NA	15,300 - 3,470,000
Sulfate		451 - 1,700,000	NA	451 - 1,700,000
Zinc		23 - 166,500	82,000	82,000

[a]Of the municipal solid waste, 5 percent will be incinerated and 95 percent will be landfilled.

[b] I: National estimates based on reported ranges of concentrations (Table VII).
II: National estimates based on extrapolation of data for a single well designed landfill (Reference 17); probably approximates the national average.

[c]NA: Data not available.

[d]Gases generated nationally in 1991 by municipal solid waste landfilled in 1990.

[e]Water use for residue quenching, fly ash conveying, and flue gas scrubbing: 3 tons water/ton incinerated municipal solid waste (assumes water recirculation) (Reference 14).

DISCUSSION: TABLE IX

In Table IX are listed the projected quantities of pollutants that will enter the environment in 1990* as the result of municipal solid disposal in 1990 by mass burning, landfill, and resource recovery. Pollutant masses were calculated on the basis of the 1990 disposal scenario that includes resource recovery (Table II), the pollutant concentrations and emission factors projected for 1990 (Table VII), and the projected volume of landfill leachate in 1990. Calculations were based on the following assumptions:

- In 1990, there will be the equivalent of 50 large scale resource recovery facilities, each processing an average of 2000 tons of municipal solid waste daily with a total annual capacity of 30 million tons.
- Half of the resource recovery facilities will treat the municipal solid waste by front-end processing with separation of refuse-derived fuel (RDF), ferrous metals, aluminum, and glass. The RDF will be cofired with coal at a 20:80 ratio (on the basis of heat input to boiler).
- Half of the resource recovery facilities will handle the municipal solid waste by mass burning with energy recovery and subsequent recovery of ferrous metals, aluminum, and glass from the residue.

*Quantities of pollutants from landfill gases represent the projected quantities that will be produced in 1991 from the municipal solid waste that will be landfilled in 1990.

DISCUSSION: TABLE IX (Continued)

- In 1990, municipal solid waste will be disposed of by:
    - o Incineration: 5 percent (10 million tons)
    - o Landfill: 80 percent (157 million tons)
    - o Resource recovery with front-end processing: 7.5 percent (15 million tons)
    - o Resource recovery with mass burning: 7.5 percent (15 million tons)
- The pollution concentrations and emission factors listed in Table VII are representative for pollutants from municipal solid waste in 1990.
- Landfill area will be about 507,000 acres in 1990 (See Appendix A, Equation IX-8b for calculation), i.e., the increase in landfill area relative to that of 1975 will be proportional to the increase in landfill capacity required for disposal of municipal solid waste (specifically, raw refuse and the residues from mass burning and resource recovery) (Table XX). Of this area, 4000 acres will be needed for disposal of residue from resource recovery.
- Leachate from landfills will amount to 91 billion gallons in 1990. (See Appendix A, Equation IX-8c for calculation.)
- Residue from resource recovery will require about one percent of total landfill capacity (Table XX) and therefore will generate one percent of the leachate volume.
- The quantity of wastewater from mass burning of municipal solid waste in 1990 will be equivalent to the water requirement for residue quenching, fly ash conveying, and flue gas scrubbing -- i.e., three tons of water per ton of municipal solid waste, with water recycling.
- The quantity of wastewater from mass burning will not be affected by heat recovery.

DISCUSSION: TABLE IX (Concluded)

- The quantity of wastewater from cofiring of coal and RDF that is attributable to the RDF fraction is three tons of water per ton of RDF, with water recycling.

- Conditions will be suitable for maximum generation of gases from landfilled municipal solid waste, and the rate of gas generation will be uniform over 25 years.

TABLE IX

PROJECTED QUANTITIES OF POLLUTANTS (in tons) FROM DISPOSAL OF MUNICIPAL SOLID WASTE (MSW) IN 1990 WITH SCENARIO FOR IMPLEMENTATION OF RESOURCE RECOVERY (RR)[a]

RECEIVING MEDIUM/POLLUTANT	PROCEDURE[a]					TOTAL
	MASS BURNING	LANDFILL OF MSW	COFIRING RDF-COAL[b]	MASS BURNING WITH ENERGY RECOVERY	LANDFILL OF RESIDUE FROM RR	
AIR						
Particulates	5100		7200	7650		19,950
SO_x (as SO_2)	10,100		24,900	15,150		50,150
NO_x (as NO_2)	5700 - 17,150		8,665	8550 - 25,750		22,900 - 51,550
CO	3450 - 10,350		NA	5175 - 15,550		8625 - 25,900
Hydrocarbons (as CH_4)	1000		20	1500		2500
Aldehydes (as Formaldehyde)	2 - 50		-2025	3 - 75		- (1900 to 2020)
Chlorides (as HCl)	18,550 - 37,050		43,950	27,850 - 55,600		90,350 - 136,500
CO_2	NA[c]	1,635,000[d]	NA	NA	0	1,635,000[d]
CH_4		594,000[d]			0	594,000[d]

TABLE IX (Continued)

PROJECTED QUANTITIES OF POLLUTANTS (in tons) FROM DISPOSAL OF MUNICIPAL SOLID WASTE (MSW) IN 1990 WITH SCENARIO FOR IMPLEMENTATION OF RESOURCE RECOVERY (RR)

RECEIVING MEDIUM/POLLUTANT	PROCEDURE[a]					TOTAL
	MASS BURNING	LANDFILL OF MSW	COFIRING RDF-COAL	MASS BURNING WITH ENERGY RECOVERY	LANDFILL OF RESIDUE FROM RR	
SURFACE WATER[e]						
Aluminum	612		∿0	918		1530
Barium	150		169	225		544
Calcium	1260		1420	1890		4570
Chloride	900 - 5790		1015 - 6515	1350 - 8685		3265 - 21,000
Chromium	4		4	6		14
Copper	1		∿0	1		2
Cyanide	0		0	0		0
Iron	9		∿0	14		23
Lead	15		∿0	23		38
Magnesium	0		0	0		0
Manganese	9		∿0	14		23
Phenols	∿0		∿0	∿0		∿0
Phosphate	60 - 270		68 - 304	90 - 405		218 - 979
Sulfate	960 - 1500		1080 - 1690	1440 - 2250		3480 - 5440
Zinc	30		∿0	45		75

TABLE IX (Continued)

PROJECTED QUANTITIES OF POLLUTANTS (in tons) FROM DISPOSAL OF MUNICIPAL SOLID WASTE (MSW) IN 1990 WITH SCENARIO FOR IMPLEMENTATION OF RESOURCE RECOVERY (RR)

RECEIVING MEDIUM/POLLUTANT	PROCEDURE[a]					TOTAL
	MASS BURNING	LANDFILL OF MSW	COFIRING RDF-COAL[b]	MASS BURNING WITH ENERGY RECOVERY	LANDFILL OF RESIDUE FROM RR	
LEACHATE[f]						
Cadmium		13			~0	13
Calcium		22,550 - 2,705,000			112	22,650 - 2,705,000
Chloride		1880 - 926,500			NA	1880 - 926,500
Chromium		466			NA	466
Copper		576			5	576
Iron, total		359,000			~0	359,000
Lead		621			~0	621
Magnesium		6385 - 5,860,000			55	6450 - 5,860,000

TABLE IX (Concluded)

PROJECTED QUANTITIES OF POLLUTANTS (in tons) FROM DISPOSAL OF MUNICIPAL SOLID WASTE (MSW) IN 1990 WITH SCENARIO FOR IMPLEMENTATION OF RESOURCE RECOVERY (RR)

RECEIVING MEDIUM/POLLUTANT	PROCEDURE[a]					TOTAL
	MASS BURNING	LANDFILL OF MSW	COFIRING RDF-COAL[b]	MASS BURNING WITH ENERGY RECOVERY	LANDFILL OF RESIDUE FROM RR	
LEACHATE[f] (cont.)						
Manganese		23 - 46,950			9	32 - 46,950
Nickel		532			∿0	532
Potassium		10,900 - 1,415,000			NA	10,900 - 1,415,000
Sodium		12,750 - 2,890,000			NA	12,750 - 2,890,000
Sulfate		376 - 1,415,000			50	426 - 1,415,000
Zinc		68,750			∿0	68,750

[a]Of the municipal solid waste, 5 percent will be incinerated, 80 percent will be landfilled, and 15 percent will undergo resource recovery (7.5 percent by front-end processing and 7.5 percent by mass burning).

[b]Emissions attributable to RDF, i.e., the difference between emissions from combustion of coal and emissions from cofiring of RDF and coal at 20:80 (based on heat input to boiler).

[c]NA: Data not available.

[d]Gases generated nationally in 1991 by municipal solid waste landfilled in 1990.

[e]Water use for residue quenching, fly ash conveying, and flue gas scrubbing: 3 tons water/ton incinerated municipal solid waste or ton RDF (assumes water recirculation) (Reference 14).

[f]Assumes 90×10^9 gallons of leachate from landfilled raw MSW and 1×10^9 gallons of leachate from landfilled residue from resource recovery.

DISCUSSION: TABLE X

The effects of resource recovery on the quantities of pollutants from 1990 municipal solid waste disposal are tabulated in Table X. The differences between quantities of pollutants emitted/discharged that would result from the two scenarios for municipal solid waste disposal in 1990 that are presented in Table II -- i.e., without and with implementation of resource recovery -- constitute the environmental effects of resource recovery. The pollutant data for the two scenarios are from Tables VIII and IX.

TABLE X

ESTIMATED CHANGE IN QUANTITIES OF POLLUTANTS (in tons) FROM DISPOSAL OF MUNICIPAL SOLID WASTE RESULTING FROM SCENARIO FOR IMPLEMENTATION OF RESOURCE RECOVERY (1990)

RECEIVING MEDIUM/ POLLUTANT	WITHOUT RESOURCE RECOVERY[a]	WITH RESOURCE RECOVERY[b]	DIFFERENCE[c]
AIR			
Particulates	5100	19,950	+14,850
SO_x (as SO_2)	10,100	50,150	+40,050
NO_x (as NO_2)	5700 - 17,150	22,900 - 51,550	+(17,200 to 34,400)
CO	3450 - 10,350	8625 - 25,900	+(5175 to 15,550)
Hydrocarbons (as CH_4)	1000	2500	+1500
Aldehydes (as Formaldehyde)	2 - 50	-(1900 to 2020)	-(1900 to 1970)
Chlorides (as HCl)	18,550 - 37,050	90,350 - 136,500	+(71,800 to 99,450)
CO_2	1,945,000	1,635,000	-310,000
CH_4	708,000	594,000	-114,000

TABLE X (Continued)

ESTIMATED CHANGE IN QUANTITIES OF POLLUTANTS (in tons) FROM DISPOSAL OF MUNICIPAL SOLID WASTE RESULTING FROM SCENARIO FOR IMPLEMENTATION OF RESOURCE RECOVERY (1990)

RECEIVING MEDIUM/ POLLUTANT	WITHOUT RESOURCE RECOVERY[a]	WITH RESOURCE RECOVERY[b]	DIFFERENCE[c]
SURFACE WATER			
Aluminum	612	1530	+918
Barium	150	544	+394
Calcium	1260	4570	+3310
Chloride	900 - 5790	3265 - 21,000	+(2365 to 5,210)
Chromium	4	14	+10
Copper	1	2	+1
Cyanide	0	0	0
Iron	9	23	+14
Lead	15	38	+23
Magnesium	0	0	0
Manganese	9	23	+14
Phenols	~0	~0	0
Phosphate	60 - 270	218 - 979	+(158 to 709)
Sulfate	960 - 1500	3480 - 5440	+(2520 to 3940)
Zinc	30	75	+45

TABLE X (Continued)

ESTIMATED CHANGE IN QUANTITIES OF POLLUTANTS (in tons) FROM DISPOSAL OF MUNICIPAL SOLID WASTE RESULTING FROM SCENARIO FOR IMPLEMENTATION OF RESOURCE RECOVERY (1990)

RECEIVING MEDIUM/ POLLUTANT	WITHOUT RESOURCE RECOVERY[a]	WITH RESOURCE RECOVERY[b]	DIFFERENCE[c]
LEACHATE			
Cadmium	16	13	-3
Calcium	27,050 - 3,245,000	22,650 - 2,705,000	-(4400 to 540,000)
Chloride	2255 - 1,110,000	1880 - 926,500	-(375 to 183,500)
Chromium	555	466	-89
Copper	688	576	-112
Iron, total	428,500	359,000	-69,500
Lead	741	621	-120
Magnesium	7660 - 7,030,000	6450 - 5,860,000	-(1210 to 1,170,000)
Manganese	27 - 56,350	32 - 46,950	+5 to -9400
Nickel	635	532	-103

TABLE X (Concluded)

ESTIMATED CHANGE IN QUANTITIES OF POLLUTANTS (in tons) FROM DISPOSAL OF MUNICIPAL SOLID WASTE RESULTING FROM SCENARIO FOR IMPLEMENTATION OF RESOURCE RECOVERY (1990)

RECEIVING MEDIUM/ POLLUTANT	WITHOUT RESOURCE RECOVERY[a]	WITH RESOURCE RECOVERY[b]	DIFFERENCE[c]
LEACHATE			
Potassium	13,050 - 1,700,000	10,900 - 1,415,000	-(2150 to 285,000)
Sodium	15,300 - 3,470,000	12,750 - 2,890,000	-(2550 to 580,000)
Sulfate	451 - 1,700,000	426 - 1,415,000	-(25 to 285,000)
Zinc	82,000	68,750	-13,250

[a]Scenario: 5 percent of municipal solid waste (10×10^6 tons) will be incinerated and 95 percent (187×10^6 tons) will be landfilled.

[b]Scenario: 5 percent of municipal solid waste (10×10^6 tons) will be incinerated, 80 percent (157×10^6 tons) will be landfilled, and 15 percent (30×10^6 tons) will undergo resource recovery (15×10^6 tons by front-end processing and 15×10^6 tons by mass burning).

[c]"Plus" indicates an increase in emissions, "minus" a decrease.

DISCUSSION: TABLE XI

The estimated quantities of ferrous metals, aluminum, and glass that would be recoverable from municipal solid waste in 1990 under the scenario for resource recovery (Table II) are given in Table XI. Also included are data for refuse-derived fuel and for raw refuse. The calculations were based on the following assumptions:

- In 1990, 30 x 10^6 tons of municipal solid waste will be processed for resource recovery, half by front-end processing and half by mass burning.
- The composition of municipal solid waste in 1990 will be the same as its typical composition in 1975 (Table III).
- Recovery efficiencies for ferrous metals, aluminum, and glass will be the same for front-end separation and recovery after mass burning.
- Recovery efficiencies will be the same in 1990 as those demonstrated in 1977.

TABLE XI

ESTIMATED QUANTITIES OF MATERIALS RECOVERABLE FROM MUNICIPAL SOLID WASTE (MSW) IN 1990 UNDER SCENARIO FOR RESOURCE RECOVERY

MATERIAL	CONTENT IN MSW (%)	QUANTITY OF RECOVERABLE MATERIAL PROCESSED BY RR[a] (ton)	DEMONSTRATED[b] RECOVERY EFFICIENCY (%)	QUANTITY RECOVERABLE (ton)
Ferrous Metals	9	2,700,000	95[c]	2,565,000
Aluminum	1	300,000	75[d]	225,000
Glass	10	3,000,000	70[d,e]	2,100,000
Combustible Materials	79	11,850,000		
RDF			75[f]	11,250,000
Raw Refuse		15,000,000[g]		

[a] Assumes that 30×10^6 tons of MSW will be processed for resource recovery (RR).

[b] Demonstrated as of 1977.

[c] Reference 25.

[d] Reference 26.

[e] Reference 27.

[f] Light fraction comprises 75 percent of input to front-end processing (Reference 28).

[g] Quantity of raw refuse that will undergo mass burning for energy and materials recovery.

DISCUSSION: TABLE XII

The environmental effects of producing steel from scrap ferrous metals (recovered from municipal solid waste) rather than from virgin materials were determined, and the data on emission factors and quantities of pollutants are presented in Table XII. The calculations were based on the following assumptions:

- In 1990, 2,565,000 tons of ferrous metals will be recovered from the 30 x 10^6 tons of municipal solid waste that will be processed for resource recovery.
- All the ferrous metals recovered from municipal solid waste will be recycled and will replace virgin material in the production of steel.
- In 1990, steel will be produced by the same processes and in the same relative quantities as in 1976 (Reference 29):
    - o Open hearth furnaces: 18.4%
    - o Basic oxygen furnaces: 62.4%
    - o Electric arc furnaces: 19.2%
- In steel production from virgin materials, one ton of pig iron will yield one ton of steel and pig iron production will require the amount of coke manufactured from one ton of coal.
- In steel production from recovered materials, one ton of scrap ferrous metals will yield one ton of steel.

DISCUSSION: TABLE XII (Concluded)

- Emission factors for uncontrolled and controlled emissions from the various stages of steel production in 1990 will be the same as those listed for 1972-1973 in the USEPA publication "Compilation of Air Pollutant Emission Factors," 2nd edition (References 30 and 31).

- All emission sources in 1990 will be equipped with pollution controls that are effective to the level of control indicated by the emission factors for controlled emissions (References 30 and 31).

TABLE XII

POLLUTANTS ASSOCIATED WITH STEEL PRODUCTION

RECEIVING MEDIUM/POLLUTANT	EMISSION FACTORS (lb/ton steel)						QUANTITIES OF POLLUTANTS IN 1990[c] (ton)		
	1975				1990				
	FROM VIRGIN MATERIAL[a]		FROM RECOVERED MATERIAL[b]		FROM VIRGIN MATERIAL	FROM RECOVERED MATERIAL	WITHOUT RESOURCE RECOVERY[d]	WITH RESOURCE RECOVERY	DIFFERENCE[e]
	UNCONTROLLED	CONTROLLED	UNCONTROLLED	CONTROLLED					
AIR									
Total particulates	228	5.5	37	0.37	5.5	0.37	7055	475	-6580
Particulate fluorides (CaF_2)	0.2	0.002	0.2	0.002	0.002	0.002	3	3	0
Gaseous fluorides (HF)	0.02	0.002	0.02	0.002	0.002	0.002	3	3	0
CO	1885	1885	90	90	1885	90	2,420,000	115,500	-2,305,000
SO_2	4.02	4.02	~0	~0	4.02	~0	5155	0	-5155
NO_2	0.04	0.04	~0	~0	0.04	~0	51	0	-51
NH_3	0.18	0.18	~0	~0	0.18	~0	231	0	-231
Hydrocarbons (as CH_4)	4.2	4.2	~0	~0	4.2	~0	5385	0	-5385
Total air pollutants[f]	242[f]		34[f]				310,000	44,000	-266,000
SURFACE WATER									
Total water pollutants[f]	135[f]		33[f]				173,000	42,000	-131,000

[a] Includes emissions from coke manufacturing (Reference 30), pig iron production (Reference 31), and steel production (Reference 31).

[b] Emissions from steel production (Reference 31); emissions will be lower if scrap is processed in steel foundries (Reference 32).

[c] For fraction of total production that would be produced from scrap ferrous metals recovered from municipal solid waste, i.e., 2,565,000 tons of steel.

[d] Does not include pollutants from mining virgin materials (primarily iron ore, coal, and limestone).

[e] "Plus" indicates an increase in emissions, "minus" a decrease.

[f] Reference 27.

DISCUSSION: TABLE XIII

The environmental effects of producing aluminum from scrap aluminum recovered from municipal solid waste rather than from virgin materials were determined, and the data on emission factors and quantities of pollutants are presented in Table XIII. The calculations were based on the following assumptions:

- In 1990, 225,000 tons of aluminum will be recovered from the 30 x 10^6 tons of municipal solid waste that will be processed for resource recovery.
- All the aluminum recovered from municipal solid waste will be recycled and will replace virgin material in the production of aluminum.
- In 1990, aluminum will be produced by the same processes and in the same relative quantities as in 1970 (Reference 33):
    - o Electrolysis in prebaked cells: 61.9%
    - o Electrolysis in horizontal-stud Soderberg cells: 25.5%
    - o Electrolysis in vertical-stud Soderberg cells: 12.6%
- Production of aluminum from virgin materials in 1990 will be the same as that in 1975 (Reference 34), i.e., 4.5 tons of bauxite will be required to produce the two tons of alumina required for production of one ton of primary aluminum.

DISCUSSION: TABLE XIII (Concluded)

- Production of aluminum from recycled materials in 1990 will be 80 percent* efficient, i.e., 0.8 tons of primary aluminum will be produced in secondary aluminum operations from each ton of scrap aluminum recovered from municipal solid waste.
- In 1990, half of the scrap aluminum will be processed in sweating furnaces and half in reverberatory furnaces.
- Emission factors for uncontrolled and controlled emissions from the various stages of aluminum production in 1990 will be the same as those listed for 1972-1973 in the USEPA publication "Compilation of Air Pollutant Emission Factors," 2nd edition (References 33 and 35).
- All emission sources in 1990 will be equipped with pollution controls that are effective to the level of control indicated by the emission factors for controlled emissions (References 33 and 35).

*Efficiency of aluminum recovery from scrap ranges from 60 to 70 percent for contaminated scrap to 98 percent for high grade, well segregated scrap (Reference 34).

TABLE XIII

POLLUTANTS ASSOCIATED WITH ALUMINUM PRODUCTION

POLLUTANT	EMISSION FACTORS (lb/ton aluminum)						QUANTITIES OF POLLUTANTS IN 1990[c] (ton)		
	1975				1990				
	FROM VIRGIN MATERIAL[a]		FROM RECOVERED MATERIAL[b]		FROM VIRGIN MATERIAL	FROM RECOVERED MATERIAL	WITHOUT RESOURCE RECOVERY[d]	WITH RESOURCE RECOVERY	DIFFERENCE[e]
	UNCONTROLLED	CONTROLLED	UNCONTROLLED	CONTROLLED					
Total particulates[f]	524	12	12	2.9	12	2.9	1080	261	-819
Particulate fluorides	18	0.35	NA[g]	NA	0.35	NA	32	NA	NA
Gaseous fluorides (HF)	27	0.35	NA	NA	2.7[h]	NA	243	NA	NA

[a]Includes emissions from bauxite grinding, calcining of aluminum hydroxide, and production of primary aluminum (Reference 33).

[b]Emissions from secondary aluminum operations (Reference 35).

[c]For fraction of total production that can be produced from the 225,000 tons of scrap aluminum recovered from municipal solid waste, i.e., 180,000 tons of aluminum.

[d]Does not include pollutants from mining virgin materials (primarily bauxite).

[e]"Plus" indicates an increase in emissions, "minus" a decrease.

[f]Includes particulate fluorides.

[g]NA: Data not available.

[h]Assumes the 90-percent control efficiency reported achievable with the most up-to-date (1975) technology (Reference 34).

DISCUSSION: TABLE XIV

The environmental effects of producing glass from cullet recovered from municipal solid waste rather than from virgin materials were studied, and the data on emission factors and quantities of air pollutants are presented in Table XIV. The calculations were based on the following assumptions:

- In 1990, 2,100,000 tons of glass will be recovered from the 30 x 10^6 tons of municipal solid waste that will be processed for resource recovery.
- All the glass recovered from municipal solid waste will be recycled and will replace virgin materials in the production of soda-lime glass containers.
- The yield in production of soda-lime glass from virgin material in 1990 will be 85 percent, i.e., fusion loss will amount to 15 percent (Reference 36).
- The yield in production of soda-lime glass from cullet in 1990 will be 100 percent (Reference 36).
- All emissions from glass manufacture in 1990 will meet the limitations specified in the Connecticut Air Pollution Control Regulations (Reference 37).
- Reduction in emissions attributable to cullet will be proportional to the amount of cullet in the process weight (i.e., feed).
- Rate of emissions will be independent of the pull on the furnace.

TABLE XIV

POLLUTANTS ASSOCIATED WITH GLASS PRODUCTION

POLLUTANT	EMISSION FACTORS (lb/ton glass)				QUANTITIES OF POLLUTANTS IN 1990[c] (ton)		
	1975[a]		1990[b]				
	FROM VIRGIN MATERIAL	FROM RECOVERED MATERIAL	FROM VIRGIN MATERIAL	FROM RECOVERED MATERIAL	WITHOUT RESOURCE RECOVERY[d]	WITH RESOURCE RECOVERY	DIFFERENCE[e]
Particulates	2[f]	NA[g]					
	3.3[h]	0.2[h]	3.3	0.2	3465	210	-3255
Total air emissions[i]	28[i]	22 - 26[i]			29,400	23,100 - 27,300	-(2,100 to 6,300)

[a]Uncontrolled emissions.

[b]Controlled emissions assuming scrubber operating at 90-percent control efficiency.

[c]For fraction of total production that would be produced from cullet recovered from municipal solid waste, i.e., 2,100,000 tons of glass.

[d]Does not include pollutants from mining virgin materials.

e"Plus" indicates an increase in emissions, "minus" a decrease.

[f]Reference 38.

[g]NA: Data not available

[h]Based on Connecticut Air Pollution Control Regulations (Reference 37) and experience of Glass Containers Corporation in Dayville, CN (References 36 and 39).

[i]Reference 27. "Virgin material" contained 15 percent cullet whereas "recovered material" was 60 percent cullet.

DISCUSSION: TABLE XV

The effects of substituting materials recovered from municipal solid waste for virgin materials in the production of steel, aluminum, and glass are summarized in Table XV. The data on quantities of pollutants are derived from Tables XII, XIII, and XIV, respectively.

TABLE XV

EFFECT OF IMPLEMENTATION OF MATERIALS RECOVERY FROM MUNICIPAL SOLID WASTE ON QUANTITIES OF POLLUTANTS FROM PRODUCTION OF STEEL, ALUMINUM, AND GLASS (1990)[a]

RECEIVING MEDIUM/POLLUTANT	SOURCE			TOTAL DIFFERENCE[b]
	STEEL PRODUCTION	ALUMINUM PRODUCTION	GLASS PRODUCTION	
AIR				
Total particulates	-6580	-819	-3255	-10,654
Particulate fluorides	0	NA[c]	NA	0
Gaseous fluorides	0	NA	NA	0
CO	-2,305,000	NA	NA	-2,305,000
SO_2	-5155	NA	NA	-5155
NO_2	-51	NA	NA	-51
NH_3	-231	NA	NA	-231
Hydrocarbons	-5385	NA	NA	-5385

[a] In tons. These data are for those portions of steel, aluminum, and glass production in which materials recovered from municipal solid wastes will replace virgin materials; the data are not for total 1990 production.

[b] Does not include pollutants from mining virgin materials. "Plus" indicates an increase in emissions, "minus" a decrease.

[c] NA: Data not available.

DISCUSSION: TABLE XVI

Production of steel, aluminum, and glass from recycled material requires less energy than production from virgin materials. The energy conservation that would result from substituting materials recovered from municipal solid waste for virgin materials in the production of these three substances is tabulated in Table XVI. The calculations were based on the following assumptions.

- In 1990, 30 million tons of municipal solid waste will be processed for resource recovery (Table II), and 2,565,000 tons of scrap ferrous metals, 225,000 tons of scrap aluminum, and 2,100,000 tons of glass cullet will be recovered (Table XI).
- All the recovered ferrous metals, aluminum, and glass will be used in materials production as replacement for virgin materials.
- Production of iron and steel, aluminum, and glass from materials recovered from municipal solid waste will amount to 2,565,000 tons, 180,000 tons, and 2,100,000 tons, respectively in 1990 (see Tables XII, XIII, and XIV).
- Energy requirements for materials production and for resource recovery processing will be the same in 1990 as in 1975.
- Energy requirements for resource recovery may be allocated among the recovered materials in proportion to their relative contents in municipal solid waste.

TABLE XVI

ESTIMATED ENERGY CONSERVATION IN MATERIALS PRODUCTION RESULTING FROM UTILIZATION OF RECOVERED MATERIALS (1990)

ENERGY REQUIREMENT	MATERIAL			TOTAL ENERGY SAVINGS	
	FERROUS METALS	ALUMINUM	GLASS	10^6 Btu	10^6 BCOE
For Production from Virgin Material[a] (10^6 Btu/ton of product)	23.3[f]	97 - 138[g]	17.2[h]		
For Production from Recovered Material[b] (10^6 Btu/ton of product)	6.1[f]	6 - 25[g]	10.55[h]		
For 1990 Production without Implementation of Resource Recovery[a,c] (10^6 Btu)	59,764,500	(17.46 to 24.84) x 10^6	36,120,000		
For 1990 Production with Implementation of Resource Recovery[b,c] (10^6 Btu)	15,646,500	(1.08 to 4.5) x 10^6	22,155,000		
For Resource Recovery[d] (10^6 Btu)	540,000	60,000	600,000		
Net Difference[e] (10^6 Btu)	43,578,000	(16.32 to 20.28) x 10^6	13,365,000	73,263,000 to 77,223,000	13.1 - 13.8
(%)	73	82 - 93	37		
Reported Energy Conservation (%)	74[f]	96[i]	6[j] (-3)[j,k] 10 - 15[l]		

[a]Does not include energy requirements for mining and for transportation of virgin materials.

[b]Does not include energy requirements for collection and transportation of municipal solid waste and for transportation of recovered materials.

[c]For those portions of 1990 production of steel, aluminum, and glass in which materials recovered from municipal solid waste would replace virgin material, i.e., not for total production.

[d]Based on 0.2 x 10^6 Btu/ton of MSW (References 40 and 41).

[e]Energy conservation in materials production as the result of implementation of resource recovery from municipal solid waste and substitution of recovered materials for virgin materials.

[f]References 27 and 29.

[g]Reference 34.

[h]Calculated from data in References 27 and 39 (see Appendix A).

[i]Reference 41.

[j]Data for difference between 15 and 60 percent cullet in process feed (Reference 27).

[k]Increased energy requirement.

[l]Data for difference between 20 and 50 percent cullet in process feed (Reference 39).

DISCUSSION: TABLE XVII

Resource recovery from municipal solid waste includes recovery of the energy that is inherent in the waste. It is assumed that the energy in municipal solid waste will be recovered by mass burning of the raw refuse in waterwall incinerators and by cofiring of the refuse-derived fuel with coal and that the recovered energy will replace some energy production from coal. In Table XVII are listed the emission factors for coal combustion, mass burning of raw refuse, and cofiring with coal of refuse-derived fuel. The emission factors for 1990 were based on the following assumptions:

- Pollution control efficiency in 1990 will be equivalent to the degree of control that was attainable in 1975, and new sources will be in compliance with the level of control specified in 1978.
- Emissions from municipal incinerators in 1990 will be the same as those from the Harrisburg, PA incinerator (360 tons per day, travelling grate, Martin process) as monitored in 1975. Energy recovery will not affect emissions.
- Emissions from cofiring coal and RDF in 1990 will be the same as those from the Ames, IA power plant (coal-RDF at 80:20, 80 percent load, stoker boiler #5, 7.5 MW) as monitored in 1977 except for particulate and SO_x emissions which will be in compliance with 1978 New Source Performance Standards for Coal-Fired Power Plants.

DISCUSSION: TABLE XVII (Concluded)

- Combustion efficiences in 1990 will be the same as those in 1978, that is:
  - Coal: 100 percent
  - Refuse-derived fuel: 65 percent
  - Municipal solid waste (raw refuse): 60 percent

TABLE XVII

POLLUTANTS ASSOCIATED WITH ENERGY PRODUCTION[a]

POLLUTANT	EMISSION FACTORS (1990)				
	COAL COMBUSTION[b]		COFIRING COAL-RDF[c]	MASS BURNING OF MSW[d]	
	lb/ton	lb/10^6 Btu	lb/10^6 Btu	lb/ton	lb/10^6 Btu
Particulates	2	0.1[e]	0.1[e]	1.02	0.20
SO_x (as SO_2)	24	1.2[e]	1.2[e]	2.02[f]	0.39
NO_x (as NO_2)	14	0.7[e]	0.16	1.14 - 3.43	0.22 - 0.66
CO	1[g]	0.05	NA[h]	0.69 - 2.07	0.13 - 0.40
Hydrocarbons (as CH_4)	0 - 0.3[g]	0 - 0.015	0.0002	0.2[i]	0.039
Aldehydes (as Formaldehyde)	0 - 0.005[g]	0 - 0.00025	0.0086	0.0004 - 0.01[i]	~ 0 - 0.0019
Chlorides (as HCl)	0.3	0.015[j]	0.20	3.71 - 7.41	0.72 - 1.44

[a] BTU: - Energy output.

[b] Average heating value of coal: 10,000 Btu/pound.

[c] Derived from 1977 data for Ames, Iowa power plant cofiring refuse-derived fuel (RDF) and coal at 20:80 based on heat input to boiler (Reference 20). Average heating values were 5757 Btu/pound RDF and 9500 Btu/pound coal.

[d] Based on data for Harrisburg, PA incinerator with emission controlled by electostatic precipitator (Reference 23). Average heating value of raw refuse was 4300 Btu/pound.

[e] Current (1978) New Source Performance Standard for Coal-Fired Power Plants (Reference 22).

[f] Sulfur content of municipal solid waste: 0.1 percent.

[g] References 42 and 43.

[h] NA: Data not available.

[i] Reference 24.

[j] Derived from data for Ames, Iowa power plant burning coal only (Reference 20).

DISCUSSION: TABLE XVIII

Two scenarios for energy production in 1990, as related to municipal solid waste, are considered. These are (a) projected energy production by coal combustion (Reference 44), and (b) projected energy production from coal with energy recovery from municipal solid waste replacing some of the energy derived by coal combustion. The quantities of pollutants that would be emitted during this specific portion of total energy production in 1990 with these two scenarios have been calculated, and the data are presented in Table XVIII. The calculations were based on the following assumptions:

- Coal consumption for power generation in 1990 will be 1036 x 10^6 tons without implementation of resource recovery.
- In 1990, 30 x 10^6 tons of municipal solid waste (MSW) will be processed for resource recovery. Refuse-derived fuel (RDF) will be produced from half of this quantity of MSW, and half will undergo mass burning with energy recovery.
- In 1990, energy recovery from municipal solid waste will replace some energy production from coal.
- In 1990, the characteristics of these sources of energy will be:

Source	Heating Value	Combustion Efficiency
Coal	20 x 10^6 Btu/ton	100%
RDF	11 x 10^6 Btu/ton	65%
Raw refuse	9 x 10^6 Btu/ton	60%

DISCUSSION: TABLE XVIII (Concluded)

- The emission factors for coal combustion, cofiring of RDF and coal at 20:80 based on heat input to boiler, and mass burning of raw refuse (MSW) as listed in Table XVII will be valid for fuels with these characteristics.

- Energy recovery from municipal solid waste in 1990 will amount to 161.4×10^{12} Btu or 0.8% of the power that otherwise would be generated by coal combustion (see Appendix A, Equations XVIII-3 for calculations).

- With energy recovery from municipal solid waste, energy will be produced by the following methods:

    - o Coal combustion: 96.8 percent
    - o Cofiring of RDF with coal at 20:80 ratio: 2.8 percent
    - o Mass burning of raw refuse in waterwall incinerators: 0.4 percent

TABLE XVIII

PROJECTED QUANTITIES OF POLLUTANTS FROM ENERGY PRODUCTION IN 1990[a]

POLLUTANT	QUANTITIES OF POLLUTANTS (ton)				
	WITHOUT RESOURCE RECOVERY	WITH SCENARIO FOR RESOURCE RECOVERY			
	COAL (100%)	COAL COMBUSTION (96.8%)	COFIRING COAL-RDF[b] (2.8%)	MASS BURNING[c] (0.4%)	TOTAL
Particulates	1,036,000	1,003,180	28,770	8100	1,040,050
SO_x (as SO_2)	12,432,000	12,038,160	345,240	15,800	12,399,200
NO_x (as NO_2)	7,252,000	7,022,260	46,030	8910 - 26,730	7,077,200 - 7,095,020
CO	518,000	501,590	NA[d]	5270 - 16,200	506,860 - 517,790
Hydrocarbons (as CH_4)	<155,400	<150,480	~0	1580	< 152,060
Aldehydes (as Formaldehyde)	<2590	< 2510	2475	< 75	< 5060
Chlorides (as HCl)	155,400	150,480	57,540	29,160 - 58,320	237,180 - 266,340

[a]For fraction of total energy production that would be produced from coal: with resource recovery, energy recovery from municipal solid waste will replace some of the coal. Percentages indicate proportion of energy produced from each fuel/by each method.

[b]Refuse-derived fuel (RDF) cofired with coal at 20:80 based on heat input to boiler.

[c]Mass burning of raw refuse in waterwall incinerator.

[d]NA: Data not available.

DISCUSSION: TABLE XIX

Under the scenario for resource recovery from municipal solid waste (Tables II and XI), energy will be recovered and will replace some coal combustion for energy production (Table XVIII). The effects of this replacement on the quantities of pollutants that would be emitted in 1990 during energy production from coal are summarized in Table XIX.

TABLE XIX

ESTIMATED CHANGE IN QUANTITIES OF POLLUTANTS FROM ENERGY PRODUCTION RESULTING FROM ENERGY RECOVERY FROM MUNICIPAL SOLID WASTE (1990)

POLLUTANT	WITHOUT RESOURCE RECOVERY[a] (ton)	WITH SCENARIO FOR RESOURCE RECOVERY[b] (ton)	DIFFERENCE[c] (ton)
Particulates	1,036,000	1,040,050	+4050
SO_x (as SO_2)	12,432,000	12,399,200	-32,800
NO_x (as NO_2)	7,252,000	7,077,200 - 7,095,020	-(156,980 to 174,800)
CO	518,000	506,860 - 517,790	-(210 to 11,140)
Hydrocarbons (as CH_4)	<155,400	<152,060	-3340
Aldehydes (as Formaldehyde)	<2590	< 5060	+2470
Chlorides (as HCl)	155,400	237,180 - 266,340	+(81,780 to 110,940)

[a] For fraction of total energy production that would be produced from coal.

[b] Energy recovery from municipal solid waste will replace some of the energy production from coal.

[c] Effect: "Plus" indicates an increase in emissions, "minus" a decrease.

DISCUSSION: TABLE XX

Implementation of the scenario for resource recovery from municipal solid waste (MSW) will affect the landfill capacity required for disposal of the MSW. This effect on the landfill capacity that would be needed to dispose of the MSW that will be generated in 1990 is tabulated in Table XX. Indirect effects of resource recovery such as the differences in quantities of solid wastes that would derive from mining activities, coal combustion, and pollution control measures have not been considered.

The calculations were based on the following assumptions:

- The scenario for resource recovery in 1990 (Table II) will be implemented, i.e., 30 million tons of municipal solid waste will be processed in 1990 for resource recovery, half by front-end processing and half by mass burning.
- Estimated densities of landfilled materials are valid.

TABLE XX

EFFECT OF IMPLEMENTATION OF RESOURCE RECOVERY ON LANDFILL CAPACITY REQUIRED FOR DISPOSAL OF MUNICIPAL SOLID WASTE IN 1990

PROCEDURE	WEIGHT REDUCTION (%)	DENSITY OF REFUSE/RESIDUE (lb/cu yd)	WITHOUT RESOURCE RECOVERY				WITH SCENARIO FOR RESOURCE RECOVERY				DIFFERENCE[b] (acre-ft)
			%[a]	REFUSE/RESIDUE WEIGHT (10^6 ton)	REFUSE/RESIDUE VOLUME (10^6 cu yd)	REQUIRED LANDFILL CAPACITY (acre-ft)	%[a]	REFUSE/RESIDUE WEIGHT (10^6 ton)	REFUSE/RESIDUE VOLUME (10^6 cu yd)	REQUIRED LANDFILL CAPACITY (acre-ft)	
Disposal by Incineration	75[c]	2700[d]	5	2.5	1.85	1150	5	2.5	1.85	1150	0
Disposal by Landfilling	0	800[e]	95	187	467.5	289,760	80	157	392.5	243,270	-46,490
Resource Recovery[f]	88	2000	0				15	3.6	3.6	2230	+2230
TOTAL				~190 10^6 tons	~470 10^6 cu yd	290,910 acre-feet		~165 10^6 tons	~400 10^6 cu yd	246,650 acre-feet	-44,260[g]

[a] Percentage indicates proportion (by weight) of municipal solid waste that is subject to each procedure. See Table II for scenarios.

[b] "Plus" indicates an increase in required landfill capacity, "minus" a decrease.

[c] Reference 45.

[d] Reference 12.

[e] For well compacted municipal solid waste in landfill (Reference 2).

[f] Based on data for Ames IA resource recovery facility (References 46 and 47), Harrisburg PA incinerator (Reference 23), RESCO operations in Saugus MA (Reference 48), Chicago IL Southwest Processing Plant (Reference 28), and Chicago IL Northwest Incinerator (Reference 49). Does not include residue from coal in cofiring.

[g] Does not include reductions in mining wastes that would result from substitution of recovered materials for virgin materials in production of iron and steel, aluminum, glass, and energy nor the reductions in solid wastes from materials and energy production.

DISCUSSION: TABLE XXI

The effects on the environment of implementation of the scenario for resource recovery from municipal solid waste in 1990 (Table II) are summarized in Table XXI. The direct effects of this scenario are (a) the changes in quantities of pollutants that will be emitted/discharged to the air/surface and ground waters as the result of disposal procedures, and (b) the change in landfill capacity that will be needed to dispose of 1990's municipal solid waste and the residues of the different disposal procedures. These data are from Tables X and XX, respectively.

The indirect effects of resource recovery from municipal solid waste derive from the recovery of materials and energy and their substitution for virgin materials in the production of materials (specifically steel, aluminum, and glass) and energy. The secondary effects considered here are (a) the changes in the quantities of pollutants that will be emitted/discharged to the environment during materials and energy production, and (b) the conservation in energy required for materials production as well as the recovery of energy from municipal solid waste that will result from this substitution of recovered materials for virgin materials.

DISCUSSION: TABLE XXI (Concluded)

These data are from Tables XV and XIX and from Tables XVI and XVIII, respectively. Reduction in quantities of pollutants and solid wastes and energy conservation that would result from not mining raw materials, reduction in solid wastes from materials production, and reduction in residue from coal combustion were not included in this study.

TABLE XXI

SUMMARY OF THE EFFECTS ON THE ENVIRONMENT OF IMPLEMENTATION OF RESOURCE RECOVERY IN ACCORDANCE WITH THE SCENARIO FOR 1990:

I. AIR EMISSIONS[a]

POLLUTANT	DIRECT EFFECTS[b]	SECONDARY EFFECTS[c]			
	DISPOSAL OF MSW	MATERIALS PRODUCTION	ENERGY PRODUCTION[d]	TOTAL	NET EFFECTS[e]
Particulates, total	+14,850	-10,654	+4050	-6604	+1046
SO_x (as SO_2)	+40,050	-5155	-32,800	-37,955	-22,805
NO_x (as NO_2)	+(17,200 to 34,400)	-51	-(156,980 to 174,800)	-(157,031 to 174,851)	-(131,296 to 166,316)
CO	+(5175 to 15,550)	-2,305,000	-(210 to 11,140)	-(2,305,210 to 2,316,140)	-(2,289,660 to 2,310,965)
Hydrocarbons (as CH_4)	+1500	-5385	-3340	-8725	-7245
Aldehydes (as formaldehyde)	-(1900 to 1970)	NA[f]	+2470	+2470	+(2525 to 2595)
Chlorides (as HCl)	+(71,800 to 99,450)	NA	+(81,780 to 110,940)	+(81,780 to 110,940)	+(109,630 to 166,440)
Particulate Fluorides	0	0	NA		0
Gaseous Fluorides	0	0	NA		0
NH_3	NA	-231	NA	-231	-231
CO_2	-310,000	NA	NA	NA	-310,000
CH_4	-114,000				-114,000

[a] Tons that will be emitted in 1990.

[b] Direct effects of resource recovery on environmental impact of municipal solid waste disposal. Includes emissions attributable to refuse-derived fuel (RDF).

[c] Indirect environmental effects of using recovered materials to replace virgin materials in materials and energy production. Does not include environmental effects of mining virgin materials or transporting virgin and recovered materials.

[d] Includes pollutants from cofiring of coal and RDF. Credit is given for emissions from coal not burned.

[e] Sum of direct and indirect effects of resource recovery corrected to eliminate double counting of the emissions attributable to RDF (which are included in both direct and secondary effects). "Plus" indicates an increase in emissions, "minus" a decrease.

[f] NA: Data not available.

TABLE XXI (Continued)

SUMMARY OF THE EFFECTS ON THE ENVIRONMENT OF IMPLEMENTATION OF RESOURCE RECOVERY IN ACCORDANCE WITH THE SCENARIO FOR 1990:

II. DISCHARGES TO SURFACE WATER[a]

POLLUTANT	DIRECT EFFECTS	SECONDARY EFFECTS[b]	
	DISPOSAL OF MSW	MATERIALS PRODUCTION	ENERGY PRODUCTION
Aluminum	+918		
Barium	+394		
Calcium	+3310		
Chloride	+(2365 to 15,210)		
Chromium	+10		
Copper	+1		
Cyanide	0		
Iron	+14		
Lead	+23		
Magnesium	0		
Manganese	+14		
Phenols	0		
Phosphate	+(158 to 709)		
Sulfate	+(2520 to 3940)		
Zinc	+45		

[a]Net difference in tons of pollutants that will be discharged in 1990. "Plus" indicates an increase in pollutant discharge, "minus" a decrease.

[b]Pollutants in wastewaster from materials and energy production were not included in this study.

TABLE XXI (Continued)

SUMMARY OF THE EFFECTS ON THE ENVIRONMENT OF IMPLEMENTATION OF RESOURCE RECOVERY IN ACCORDANCE WITH THE SCENARIO FOR 1990:

III. POLLUTANTS IN LANDFILL LEACHATE[a]

POLLUTANT	DIRECT EFFECTS	SECONDARY EFFECTS[b]	
	DISPOSAL OF MSW	MATERIALS PRODUCTION	ENERGY PRODUCTION
Cadmium	-3		
Calcium	-(4400 to 540,000)		
Chloride	-(375 to 183,500)		
Chromium	-89		
Copper	-112		
Iron, total	-69,500		
Lead	-120		
Magnesium	-(1210 to 1,170,000)		
Manganese	+5 to -9400		
Nickel	-103		
Potassium	-(2150 to 285,000)		
Sodium	-(2550 to 580,000)		
Sulfate	-(25 to 285,000)		
Zinc	-13,250		

[a] Net difference in tons of pollutants that will be present in landfill leachate in 1990. "Plus" indicates an increase, "minus" a decrease.

[b] Solid wastes from mining of virgin materials and from materials and energy production were not included in this study.

TABLE XXI (Concluded)

SUMMARY OF THE EFFECTS ON THE ENVIRONMENT OF IMPLEMENTATION OF RESOURCE RECOVERY IN ACCORDANCE WITH THE SCENARIO FOR 1990:

IV. MISCELLANEOUS EFFECTS

EFFECT	DIRECT EFFECTS	SECONDARY EFFECTS		TOTAL
	MSW DISPOSAL	MATERIALS PRODUCTION	ENERGY PRODUCTION	
Requirement for Landfill Capacity (acre-feet)	-44,260[a]	b	b	-44,260[a]
Energy Recovery (Btu)			161,400,000 x 10^6	236,643,000 x 10^6 Btu
(BCOE)[c]			28,821,000	42,258,000 BCOE[c]
Energy Conservation (Btu)		~75,243,000 x 10^6		
(BCOE)[c]		13,436,000		

[a] "Minus" indicates a decrease in requirement for landfill capacity.

[b] Solid wastes from mining of virgin materials, from materials production, and from coal combustion were not included in this study.

[c] BCOE: Barrels of crude oil equivalent.

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APPENDIX A

EQUATIONS USED IN CALCULATIONS

I. GENERATION OF MUNICIPAL SOLID WASTE IN THE UNITED STATES

1. Calculation of Quantity of Municipal Solid Waste (MSW) Generated

$$Q_{MSW} = R \times P \times f_1 \times f_2 \qquad (I\text{-}1)$$

where Q_{MSW} = quantity of MSW generated during a given year in places/urbanized areas of a given population size (tons)

R = rate of MSW generation in places/urbanized areas of that size (pounds/person daily)

P = total population in places/urbanized areas of that size in that year

f_1 = conversion factor (from day to year) = 365

f_2 = conversion factor (from pounds to tons) = 1/2000

Example: Calculate the quantity of MSW that will be generated in 1990 in urbanized areas with population of more than 1,000,000

$$Q_{MSW} = \frac{5.5 \times 85{,}200{,}000 \times 365}{2000}$$

$$= 85{,}519{,}500$$

$$= \sim 85{,}500{,}000 \text{ tons MSW}$$

VI. QUANTITIES OF POLLUTANTS DERIVED FROM DISPOSAL OF MUNICIPAL SOLID WASTE (MSW) IN 1975

1. Calculation of Quantities of Air Pollutants Emitted in 1975 during Incineration of MSW

$$Q_P = Ef_P \times M_I \times f \qquad \text{(VI-1)}$$

where Q_P = quantity of a pollutant emitted during 1975 (tons)
Ef_P = emission factor for that pollutant (pounds/ton MSW incinerated)
M_I = mass of MSW disposed of by incineration in 1975 (tons)
f = conversion factor (from pounds to tons)
= 1/2000

Example: Calculate the quantity of particulates emitted during incineration of MSW in 1975

$$Q_P = \frac{30 \times 17{,}300{,}000}{2000}$$
$$= 259{,}500$$
$$= \sim 260{,}000 \text{ tons particulates}$$

2. Calculation of Quantities of Gases Generated in Landfills in 1976 by MSW Landfilled in 1975

$$Q_P = G_P \times f_1 \times M_L \times D_P \times f_2 \qquad \text{(VI-2)}$$

where Q_P = quantity of the gas that is generated in the one year from the landfilled MSW (tons)
G_P = maximum quantity of gas generation over 25 years (cubic feet/ton MSW)
f_1 = time factor (one year out of 25 years during which gas is generated)
= 1/25
M_L = mass of MSW landfilled in 1975 (tons)
D_P = density of the gas (pounds/standard cubic foot)
f_2 = conversion factor (from pounds to tons)
= 1/2000

Example: Calculate the quantity of methane generated in one year by the MSW landfilled in 1975

$$Q_P = \frac{4560 \times 155{,}500{,}000 \times 0.0415}{25 \times 2000}$$
$$= 588{,}536$$
$$= \sim 589{,}000 \text{ tons methane}$$

3. Calculation of Quantities of Pollutants Discharged to Surface Waters in Incinerator Wastewater in 1975

$$Q_P = C_P \times Q_W \times M_I \qquad \text{(VI-3)}$$

where Q_P = quantity of a pollutant discharged in incinerator wastewater (tons)
C_P = concentration of that pollutant in the quench water
Q_W = water requirement (tons/ton MSW incincerated)
M_I = quantity of MSW incinerated in 1975 (tons)

Example: Calculate the quantity of lead discharged to surface waters in incinerator wastewater in 1975

$$Q_P = \frac{0.3 \times 6 \times 17{,}300{,}000}{1{,}000{,}000}$$
$$= 31 \text{ tons lead}$$

4. Calculation of Quantities of Pollutants Present in Leachate from Landfilled MSW in 1975 (based on reported ranges of concentrations)

$$Q_P = C_P \times Q_L \times f_1 \times f_2 \qquad \text{(VI-4)}$$

where Q_P = quantity of a pollutant in landfill leachate (tons)
C_P = range of concentration of that pollutant in the leachate (ppm)
Q_L = quantity of landfill leachate (10^9 gallons)
f_1 = conversion factor (from ppm to pounds/billion gallons)
= 8345
f_2 = conversion factor (from pounds to tons)
= 1/2000

Example: Calculate the quantity of cadmium in landfill leachate in 1975

$$Q_P = \frac{(0.03 \text{ to } 17) \times 90 \times 8345}{2000}$$
$$= 11.3 \text{ to } 6383.9$$
$$= \sim(11 \text{ to } 6385) \text{ tons cadmium}$$

5. Calculation of Quantities of Pollutants Present in Leachate from Landfilled MSW in 1975 (based on data for a single landfill)

$$Q_P = C_P \times Q_L \times f_1 \times f_2 \times f_3 \qquad \text{(VI-5)}$$

where Q_P = quantity of a pollutant in landfill leachate (tons)
C_P = concentration of that pollutant in the leachate
Q_L = quantity of leachate from the one landfill
= 20,000 cubic meters/month
f_1 = conversion factor (from month to year)
= 12
f_2 = conversion factor (from grams to tons)
= 1.102×10^{-6}
f_3 = factor for extrapolating from the one landfill to the national landfill area
= $\frac{500,000}{300}$

Example: Calculate the quantity of cadmium in landfill leachate in 1975

$$Q_P = \frac{0.03 \times 20,000 \times 12 \times 1.102 \times 500,000}{300 \times 10^6}$$
$$= 13.2$$
$$= 13 \text{ tons cadmium}$$

VII. EMISSION FACTORS FOR POLLUTANTS EMITTED FROM REFUSE-DERIVED FUEL (RDF) DURING COFIRING WITH COAL

1. Calculation of Emission Factors for Air Pollutants Emitted during Coal Combustion in Boiler #5 of Ames, Iowa Power Plant in 1977

$$Ef_C = E \times HHV_C \times f \qquad \text{(VII-1)}$$

where Ef_C = emission factor for that pollutant from coal (pounds/ton coal)
E = emission rate (grams/megajoule) (Reference 20)
HHV_C = heating value of coal
= 22.4 megajoules/kilogram (Reference 21)
f = conversion factor (from grams/kilogram to pounds/ton)
= 2

Example: Calculate the emission factor for particulates from coal combustion in boiler #5 in 1977

$$Ef_C = 3.2 \times 22.4 \times 2$$
$$= 143 \text{ pounds particulates/ton coal}$$

2. Calculation of Emission Factors for Air Pollutants Emitted during Cofiring of Coal and RDF (80:20*) in Boiler #5 of Ames, Iowa Power Plant in 1977

$$Ef_F = E \times \left[(HHV_C \times HI_C) + (HHV_{RDF} \times HI_{RDF})\right] \times f \qquad \text{(VII-2)}$$

where Ef_F = emission factor for that pollutant from the fuel (pounds/ton fuel)
E = emission rate (grams/megajoule) (Reference 20)
HHV_C = heating value of coal
= 22.1 megajoules/kilogram (Reference 21)
HI_C = heat input of coal
= 67.3 percent (Reference 21)
HHV_{RDF} = heating value of RDF
= 14.9 megajoules/kilogram (Reference 21)

*Nominal ratio of heat inputs from coal and RDF, respectively.

HI_{RDF} = heat input of RDF
= 32.7 percent (Reference 21)
f = conversion factor (from grams/kilogram to pounds/ton)
= 2

Example: Calculate the emission factor for particulates from cofiring of coal and RDF (80:20*) in boiler #5 in 1977

$$Ef_F = 3.8 \times [(22.1 \times 0.673) + (14.9 \times 0.327)] \times 2$$
= 150 pounds particulates/ton fuel

3. Calculation of Emission Factors for Air Pollutants Attributable to RDF That Were Emitted during Cofiring of Coal and RDF (80:20*) in Boiler #5 of Ames, Iowa Power Plant in 1977

$$Ef_F = (Ef_C \times Q_C) + (Ef_{RDF} \times Q_{RDF}) \quad \text{(VII-3a)}$$

or

$$Ef_{RDF} = \frac{EF_F - Ef_C \times Q_C}{Q_{RDF}} \quad \text{(VII-3b)}$$

where Ef_{RDF} = emission factor for that pollutant from the RDF (pounds/ton RDF)
Ef_F = emission factor for that pollutant from the cofired coal and RDF (pounds/ton fuel) (See Equation VII-2.)
Ef_C = emission factor for that pollutant from coal (pounds/ton coal) (See Equation VII-1.)
Q_C = quantity of coal in cofiring (tons coal/ton fuel)
Q_{RDF} = quantity of RDF in cofiring (tons RDF/ton fuel)

Example 1: Calculate the emission factor for particulates that is attributable to the RDF fraction in cofiring with coal

$$Ef_{RDF} = \frac{150 - (143 \times 0.581)}{0.419}$$
= 160 pounds particulates/ton RDF in uncontrolled emissions

*Nominal ratio of heat inputs from coal and RDF, respectively.

= 6.4 pounds particulates/ton RDF in controlled emissions*
= 0.5 pound particulates/10^6 Btu**

Note: An emission of 0.5 pound particulates/10^6 Btu would be in excess of the New Source Performance Standard for Coal-Fired Power Plants (Reference 22). In order to meet the standard of 0.1 pound particulates/10^6 Btu, the maximum emission factor for particulates from RDF cofired with coal would be 1.28 pounds particulates/ton RDF.**

Example 2: Calculate the emission factor for SO_x that is attributable to the RDF fraction in cofiring with coal

$$Ef_{RDF} = \frac{28 - (45 \times 0.581)}{0.419}$$
= 4.43 pounds SO_x/ton RDF
= 0.35 pound SO_x/10^6 Btu**

Example 3: Calculate the emission factor for NO_x that is attributable to the RDF fraction in cofiring with coal

$$Ef_{RDF} = \frac{2.65 - (3.45 \times 0.581)}{0.419}$$
= 1.54 pounds NO_x/ton RDF
= 0.12 pound NO_x/10^6 Btu**

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*Assumes an electrostatic precipitator operating at 96 percent efficiency.

**In 1977 tests in Ames, Iowa of boiler #5 operating at 80-percent load and RDF cofired with coal at a nominal ratio of 20:80, the RDF had a heating value of 14.9 MJ/kg (12.82 x 10^6 Btu/ton) (Reference 21).

VIII. QUANTITIES OF POLLUTANTS DERIVED FROM DISPOSAL OF MUNICIPAL SOLID WASTE (MSW) IN 1990

1. Calculation of Quantities of Air Pollutants That Will Be Emitted in 1990 during Mass Burning of MSW

$$Q_P = Ef_P \times M_I \times f \qquad \text{(VIII-1)}$$

where Q_P = quantity of a pollutant that will be emitted in 1990 (tons)

M_I = mass of MSW that will be disposed of by incineration in 1990 (tons)

See Equation VI-1 for other definitions.

Example: Calculate the quantity of particulates that will be emitted during mass burning of MSW in 1990

$$Q_P = \frac{1.02 \times 10{,}000{,}000}{2000}$$

$$= 5100 \text{ tons particulates}$$

2. Calculation of Quantities of Gases That Will Be Generated in Landfills in 1991 by MSW That Will Be Landfilled in 1990

$$Q_P = G_P \times f_1 \times M_L \times D_P \times f_2 \qquad \text{(VIII-2)}$$

where M_L = mass of MSW that will be landfilled in 1990 (tons)

See Equation VI-2 for other definitions.

Example: Calculate the quantity of methane that will be generated in one year by the MSW that will be landfilled in 1990

$$Q_P = \frac{4560 \times 187{,}000{,}000 \times 0.0415}{25 \times 2000}$$

$$= 707{,}758$$

$$= \sim 708{,}000 \text{ tons methane}$$

3. Calculation of Quantities of Pollutants That Will Be Discharged to Surface Waters in Incinerator Wastewater in 1990

$$Q_P = C_P \times Q_W \times M_I \qquad \text{(VIII-3)}$$

where M_I = quantity of MSW that will be incinerated in 1990 (tons)

See Equation VI-3 for other definitions.

Example: Calculate the quantity of lead that will be discharged to surface waters in incinerator wastewater in 1990

$$Q_P = \frac{0.5 \times 3 \times 10{,}000{,}000}{1{,}000{,}000}$$
$$= 15 \text{ tons lead}$$

4. Calculation of Area of Municipal Landfills in 1990 and Volume of Leachate from These Landfills

4A. Calculation of Crowth Factor

$$f = \frac{LC_1}{LC_0} \qquad \text{(VIII-4a)}$$

where f = growth factor

LC_1 = landfill capacity required to dispose of MSW in 1990 if there is no resource recovery (acre-feet) (see Table XX and Equation XX-4 for calculation)

LC_0 = landfill capacity required to dispose of MSW in 1975 (acre-feet)

Calculation:

$$f = \frac{290{,}900}{243{,}000}$$
$$= 1.2$$

4B. Calculation of Landfill Area in 1990

$$A_1 = A_0 \times f \qquad \text{(VIII-4b)}$$

where A_1 = landfill area in 1990 (acres)

A_0 = landfill area in 1975 (acres)

f = growth factor (from Equation VIII-4a)

Calculation:

$$A_1 = 500{,}000 \times 1.2$$
$$= 600{,}000 \text{ acres}$$

4C. Calculation of Volume of Landfill Leachate in 1990

$$Q_{L_1} = Q_{L_0} \times f \qquad \text{(VIII-4c)}$$

where Q_{L_1} = quantity of leachate in 1990 (10^9 gallons)
Q_{L_0} = quantity of leachate in 1975 (10^9 gallons)
f = growth factor (from Equation VIII-4a)

Calculation:

$$Q_{L_1} = 90 \times 10^9 \times 1.2$$
$$= 108 \text{ billion gallons}$$

5. Calculation of Quantities of Pollutants That Will Be Present in Leachate from Landfilled MSW in 1990

5A. Calculation Based on Reported Ranges of Concentrations

$$Q_P = C_P \times Q_L \times f_1 \times f_2 \qquad \text{(VIII-5a)}$$

where Q_L = quantity of landfill leachate that will be produced in 1990 if there is no resource recovery (10^9 gallons)
See Equation VI-4 for other definitions.

Example: Calculate the quantity of cadmium in landfill leachate in 1990

$$Q_P = \frac{(0.03 \text{ to } 17) \times 108 \times 8345}{2000}$$
$$= 14 \text{ to } 7660 \text{ tons cadmium}$$

5B. Calculation Based on Data for a Single Landfill

$$Q_P = C_P \times Q_L \times f_1 \times f_2 \times f_3 \qquad \text{(VIII-5b)}$$

where f_3 = factor for extrapolating from the one landfill to the national landfill area

$$= \frac{600,000}{300}$$

See Equation VI-5 for other definitions.

Example: Calculate the quantity of cadmium in landfill leachate in 1990

$$Q_P = \frac{0.03 \times 20,000 \times 12 \times 1.102 \times 600,000}{300 \times 10^6}$$

= 16 tons cadmium

IX. QUANTITIES OF POLLUTANTS DERIVED FROM DISPOSAL OF MUNICIPAL SOLID WASTE (MSW) IN 1990 WITH IMPLEMENTATION OF RESOURCE RECOVERY

1. Calculation of Quantities of Air Pollutants That Will Be Emitted in 1990 during Mass Burning of MSW without Recovery of Heat and Other Resources

$$Q_P = Ef_P \times M_I \times f \qquad \text{(IX-1)}$$

where M_I = mass of MSW that will be disposed of in 1990 by mass burning without recovery of resources (tons)
See Equation VI-1 for other definitions.

Example: Calculate the quantity of particulates that will be emitted during mass burning of MSW in 1990

$$Q_P = \frac{1.02 \times 10{,}000{,}000}{2000}$$
$$= 5100 \text{ tons particulates}$$

2. Calculation of Quantities of Air Pollutants Attributable to RDF That Will Be Emitted during Cofiring of RDF and Coal at 20:80 in 1990

$$Q_P = Ef_P \times M_{RDF} \times f \qquad \text{(IX-2)}$$

where M_{RDF} = mass of RDF that will be cofired with coal in 1990 (tons) (Table XI)
See Equation VI-1 for other definitions.

Example: Calculate the quantity of chlorides that will be emitted from RDF during cofiring with coal in 1990

$$Q_P = \frac{7.81 \times 11{,}250{,}000}{2000}$$
$$= 43{,}931$$
$$= \sim 43{,}950 \text{ tons chlorides}$$

3. Calculation of Quantities of Air Pollutants That Will Be Emitted in 1990 During Mass Burning of MSW with Resource Recovery

$$Q_P = Ef_P \times M_{I_{RR}} \times f \qquad \text{(IX-3)}$$

where $M_{I_{RR}}$ = mass of MSW that will undergo mass burning with resource recovery in 1990 (tons)

See Equation VI-1 for other definitions.

Example: Calculate the quantity of particulates that will be emitted during mass burning of MSW with resource recovery in 1990

$$Q_P = \frac{1.02 \times 15{,}000{,}000}{2000}$$
$$= 7650 \text{ tons particulates}$$

4. Calculation of Quantities of Gases That Will Be Generated in Landfills in 1991 by MSW That Will Be Landfilled in 1990

$$Q_P = G_P \times f_1 \times M_L \times D_P \times f_2 \qquad \text{(IX-4)}$$

where M_L = mass of raw refuse that will be landfilled in 1990 (tons)

See Equation VI-2 for other definitions.

Example: Calculate the quantity of methane that will be generated in one year by the MSW that will be landfilled in 1990

$$Q_P = \frac{4560 \times 157{,}000{,}000 \times 0.0415}{25 \times 2000}$$
$$= 594{,}214$$
$$= \sim 594{,}000 \text{ tons methane}$$

5. Calculation of Quantities of Pollutants That Will Be Discharged in 1990 to Surface Waters in Incinerator Wastewater from Mass Burning of MSW without Resource Recovery

$$Q_P = C_P \times Q_W \times M_I \qquad \text{(IX-5)}$$

where M_I = mass of MSW that will be incinerated in 1990 without recovery of resources (tons)

See Equation VI-3 for other definitions.

Example: Calculate the quantity of lead that will be discharged in 1990 to surface waters in incinerator wastewater

$$Q_P = \frac{0.5 \times 3 \times 10{,}000{,}000}{1{,}000{,}000}$$
$$= 15 \text{ tons lead}$$

6. Calculation of Quantities of Pollutants Attributable to the RDF Fraction That Will Be Discharged in Wastewater from Cofiring of Coal and RDF in 1990

$$Q_P = C_P \times Q_W \times M_{RDF} \qquad \text{(IX-6)}$$

where M_{RDF} = mass of RDF (tons)
See Equation VI-3 for other definitions.

Example: Calculate the quantity of phenols attributable to the RDF fraction that will be discharged in the wastewater from cofiring of coal and RDF

$$Q_P = \frac{0.005 \times 3 \times 11{,}250{,}000}{1{,}000{,}000}$$
$$= 0.2 \text{ ton phenols}$$

7. Calculation of Quantities of Pollutants That Will Be Discharged to Surface Waters in 1990 in Wastewater from Facilities That Utilize Mass Burning for Recovery of Resources from MSW

$$Q_P = C_P \times Q_W \times M_{I_{RR}} \qquad \text{(IX-7)}$$

where $M_{I_{RR}}$ = mass of MSW that will undergo mass burning with resource recovery in 1990 (tons)
See Equation VI-3 for other definitions.

Example: Calculate the quantity of lead that will be discharged in wastewater from these facilities in 1990

$$Q_P = \frac{0.5 \times 3 \times 15{,}000{,}000}{1{,}000{,}000}$$
$$= 22.5$$
$$= \sim 23 \text{ tons lead}$$

8. Calculation of Area of Municipal Landfills in 1990, If Resource Recovery Is Implemented, and the Volume of Leachate from These Landfills

8A. Calculation of Growth Factor

$$f = \frac{LC_1}{LC_0} \qquad \text{(IX-8a)}$$

where f = growth factor
LC_1 = landfill capacity requirement in 1990 for disposal of raw refuse and residue from resource recovery (acre-feet) (See Table XX and Equation XX-3 for calculation.)
LC_0 = landfill capacity requirement in 1975 for disposal of raw refuse and incinerator residue (acre-feet)

Calculation:

$$f = \frac{246,600}{243,000}$$
$$= 1.0148$$

8B. Calculation of Landfill Area in 1990 with Resource Recovery

$$A_1 = A_0 \times f \qquad \text{(IX-8b)}$$

where A_1 = landfill area in 1990 (acres)
A_0 = landfill area in 1975 (acres)
f = growth factor (from Equation IX-8a)

Calculation:

$$A_1 = 500,000 \times 1.0148$$
$$= 507,400$$
$$= \sim 507,000 \text{ acres}$$

8C. Calculation of Volume of Leachate in 1990 with Resource Recovery

$$Q_{L_1} = Q_{L_0} \times f \qquad \text{(IX-8c)}$$

where Q_{L_1} = quantity of leachate in 1990 (10^9 gallons)
Q_{L_0} = quantity of leachate in 1975 (10^9 gallons)
f = growth factor (from Equation IX-8a)

Calculation:

$$Q_{L_1} = 90 \times 10^9 \times 1.0148$$
$$= 91.3$$
$$= \sim 91 \text{ billion gallons}$$

9. Calculation of Quantities of Pollutants That Will Be Present in Leachate from Landfilled MSW in 1990

9A. Calculation Based on Reported Ranges of Concentrations

$$Q_P = C_P \times Q_L \times f_1 \times f_2 \qquad \text{(IX-9a)}$$

where Q_L = quantity of leachate from landfilled raw refuse in 1990 (10^9 gallons)

See Equation VI-4 for other definitions.

Example: Calculate the quantity of magnesium in this portion of landfill leachate in 1990

$$Q_P = \frac{(17 \text{ to } 15{,}600) \times 90 \times 8345}{2000}$$
$$= 6384 \text{ to } 5{,}858{,}190$$
$$= \sim(6385 \text{ to } 5{,}860{,}000) \text{ tons magnesium}$$

9B. Calculation Based on Data for a Single Landfill

$$Q_P = C_P \times Q_L \times f_1 \times f_2 \times f_3 \qquad \text{(IX-9b)}$$

where $f_3 = \frac{503{,}000}{300}$

See Equation VI-5 for other definitions.

Example: Calculate the quantity of cadmium in leachate from landfilled raw refuse in 1990

$$Q_P = \frac{0.03 \times 20{,}000 \times 12 \times 1.102 \times 503{,}000}{300 \times 10^6}$$
$$= 13 \text{ tons cadmium}$$

10. Calculation of Quantities of Pollutants That Will Be Present in Leachate from Resource Recovery Residue in 1990

$$Q_{P_{RR}} = C_{P_{RR}} \times Q_{L_{RR}} \times f_1 \times f_2 \qquad \text{(IX-10)}$$

where $Q_{P_{RR}}$ = quantity of a pollutant in the leachate from landfilled resource recovery residue in 1990 (tons)

$C_{P_{RR}}$ = concentration of the pollutant in that leachate (ppm) (See Appendix B.)

$Q_{L_{RR}}$ = quantity of leachate from landfilled resource recovery residue in 1990 (10^9 gallons)

f_1 = conversion factor (from ppm to pounds/billion gallons)
= 3345

f_2 = conversion factor (from pounds to tons)
= 1/2000

Example: Calculate the quantity of manganese that will be present in leachate from the landfilled residue of resource recovery in 1990

$$Q_{P_{RR}} = \frac{2.08 \times 1 \times 8345}{2000}$$
$$= 8.7$$
$$= \sim 9 \text{ tons manganese}$$

X. CHANGES IN QUANTITIES OF POLLUTANTS THAT WOULD BE EMITTED/DISCHARGED FROM MUNICIPAL SOLID WASTE (MSW) DISPOSAL IN 1990 IF RESOURCE RECOVERY WERE IMPLEMENTED ACCORDING TO THE SCENARIO IN TABLE II

1. Calculation of the Differences in Quantities of Pollutants That Would Result from Implementation of Resource Recovery

$$\Delta Q_P = \Sigma Q_{P_{RR}} - \Sigma Q_P \qquad (X\text{-}1)$$

where ΔQ_P = the change in quantity of a pollutant that would be effected by implementation of resource recovery (tons)

$\Sigma Q_{P_{RR}}$ = total quantity of the pollutant that would be emitted/discharged in 1990 in MSW disposal with implementation of resource recovery (tons) (data from Table IX)

ΣQ_P = total quantity of the pollutant that would be emitted/discharged in 1990 in MSW disposal without resource recovery (tons) (data from Table VIII)

Example: Calculate the change in quantities of particulates that would be emitted during MSW disposal in 1990 as the result of implementation of resource recovery

$\Delta Q_P = 19{,}950 - 5100$
$= +14{,}850$ tons particulates

XI. QUANTITIES OF MATERIALS RECOVERABLE FROM MUNICIPAL SOLID WASTE (MSW) IN 1990

1. Calculation of Quantities of Recoverable Materials That Will Be Processed by Resource Recovery in 1990

$$Q_{M_P} = M_{RR} \times C_M \qquad \text{(XI-1)}$$

where Q_{M_P} = quantity of a material in MSW that will be processed by resource recovery in 1990 (tons)
M_{RR} = mass of MSW that will undergo resource recovery in 1990 (tons)
C_M = content (population) of the material in MSW in 1990

Example: Calculate the quantity of ferrous metals in the MSW that will be processed for resource recovery in 1990

$$Q_{M_P} = 30{,}000{,}000 \times 9\%$$
$$= 2{,}700{,}000 \text{ tons ferrous metals}$$

2. Calculation of Quantities of Materials That Will Be Recoverable from MSW in 1990 by Resource Recovery

$$Q_{M_R} = Q_{M_P} \times RE_M \qquad \text{(XI-2)}$$

where Q_{M_R} = quantity of a material that will be recovered from MSW in 1990 by resource recovery (tons)
Q_{M_P} = quantity of the material in MSW that will be processed by resource recovery in 1990 (tons)
RE_M = efficiency of recovering the material from MSW in 1990

Example: Calculate the quantity of aluminum that will be recoverable from MSW in 1990

$$Q_{M_R} = 300{,}000 \times 75\%$$
$$= 225{,}000 \text{ tons aluminum}$$

XII. POLLUTANTS ASSOCIATED WITH STEEL PRODUCTION

1. Calculation of the Emission Factors for Production of Steel from Virgin Materials*

$$\Sigma Ef_{P_V} = Ef_{P_C} + Ef_{P_{PI}} + Ef_{P_S} \qquad \text{(XII-1)}$$

where ΣEf_{P_V} = the aggregate emission factor for that pollutant from the production of steel from virgin materials (pounds/ton steel)

Ef_{P_C} = emission factor for that pollutant from coke manufacture (pounds/ton coal)

$Ef_{P_{PI}}$ = emission factor for that pollutant from pig iron production (pounds/ton pig iron)

Ef_{P_S} = emission factor for that pollutant from steel production (pounds/ton steel)

and where:

$$Ef_{P_S} = (Ef_{P_{S_{OHF}}} \times P_{OHF}) + (Ef_{P_{S_{BOF}}} \times P_{BOF}) + (Ef_{P_{S_{EAF}}} \times P_{EAF}) \qquad \text{(XII-1a)}$$

where $Ef_{P_{S_{OHF}}}$ = emission factor for that pollutant from steel production in an open hearth furnace (pounds/ton steel)

P_{OHF} = proportion of steel produced in open hearth furnaces in 1976
= 18.4% (Reference 29)

$Ef_{P_{S_{BOF}}}$ = emission factor for that pollutant from steel production in a basic oxygen furnace (pounds/ton steel)

P_{BOF} = proportion of steel produced in basic oxygen furnaces in 1976
= 62.4% (Reference 29)

$Ef_{P_{S_{EAF}}}$ = emission factor for that pollutant from steel production in an electric arc furnace (pounds/ton steel)

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*Assumes that one ton of steel is produced from one ton of pig iron and that the production of one ton of pig iron requires the coke manufactured from one ton of coal.

P_{EAF} = proportion of steel produced in electric arc furnaces in 1976
= 19.2% (Reference 29)

Example: Calculate the aggregate emission factor for total particulates from the production of steel from virgin materials

$$\Sigma Ef_{P_V} = 3.5 + 187 + [(17.4 \times 0.184) + (51 \times 0.624) + (11 \times 0.192)]$$

= 228 pounds particulates/ton steel

2. Calculation of the Emission Factors for Production of Steel from Recycled Materials*

$$Ef_{P_R} = Ef_{P_S}$$

$$= (Ef_{P_{S_{OHF}}} \times P_{OHF}) + (Ef_{P_{S_{BOF}}} \times P_{BOF}) + (Ef_{P_{S_{EAF}}} \times P_{EAF}) \qquad \text{(XII-2)}$$

where Ef_{P_R} = emission factor for that pollutant from the production of steel from scrap ferrous metals (pounds/ton steel)
See Equations XII-1 and XII-1a for other definitions.

Example: Calculate the emission factor for total particulates from the production of steel from scrap ferrous metals

$$Ef_{P_R} = (17.4 \times 0.184) + (51 \times 0.624) + (11 \times 0.192)$$

= 37 pounds particulates/ton steel

*Assumes that one ton of steel is produced from one ton of scrap ferrous metals.

3. Calculation of Quantities of Pollutants That Will Be Emitted/ Discharged in 1990 during Production of 2,565,000 Tons of Steel from Virgin Materals

$$Q_{P_V} = \Sigma Ef_P \times M_S \times f \qquad \text{(XII-3)}$$

where Q_{P_V} = quantity of a pollutant from production from virgin materials (tons)
ΣEf_P = the aggregate emission factor for that pollutant from the production of steel from virgin materials (pounds/ton steel)
M_S = mass of steel (tons)
f = conversion factor (from pounds to tons) = 1/2000

Example: Calculate the quantity of total particulates that would be emitted in 1990 during production of 2,565,000 tons of steel from virgin materials

$$Q_{P_V} = \frac{5.5 \times 2{,}565{,}000}{2000}$$
$$= 7054$$
$$= \sim 7055 \text{ tons particulates}$$

4. Calculation of Quantities of Pollutants That Will Be Emitted/ Discharged in 1990 during Production of 2,565,000 Tons of Steel from Scrap Ferrous Metals

$$Q_{P_R} = Ef_P \times M_S \times f \qquad \text{(XII-4)}$$

where Q_{P_R} = quantity of a pollutant from steel production from recycled materials (tons)
Ef_P = emission factor for that pollutant from the production of steel from scrap ferrous metals (pounds/ton steel)
See Equation XII-3 for other definitions.

Example: Calculate the quantity of total particulates that would be emitted in 1990 during production of 2,565,000 tons of steel from scrap ferrous metals

$$Q_{P_R} = \frac{0.37 \times 2{,}565{,}000}{2000}$$
$$= 475 \text{ tons particulates}$$

5. Calculation of Effect of Substituting Scrap Ferrous Metals for Virgin Materials in Production of 2,565,000 Tons of Steel in 1990

$$\Delta Q_P = Q_{P_R} - Q_{P_V} \qquad \text{(XII-5)}$$

where ΔQ_P = difference in quantities of a pollutant that would be emitted if scrap ferrous metal from municipal solid waste is substituted for virgin materials in steel production in 1990 (tons)

Q_{P_R} = quantity of the pollutant that would be emitted during steel production from scrap ferrous metals (tons)

Q_{P_V} = quantity of the pollutant that would be emitted during steel production from virgin materials (tons)

Example: Calculate the difference in particulate emissions that would result from substituting the scrap ferrous metals recovered from municipal solid waste for virgin materials in steel production

$$\Delta Q_P = 475 - 7055$$
$$= -6580 \text{ tons particulates}$$

XIII. POLLUTANTS ASSOCIATED WITH ALUMINUM PRODUCTION

1. Calculation of the Emission Factors for Production of Aluminum from Virgin Materials*

$$\Sigma Ef_P = (4.5 \times Ef_{P_B}) + (2 \times Ef_{P_{A_1}}) + (Ef_{P_{A_2}}) \qquad \text{(XIII-1)}$$

where ΣEf_P = the aggregate emission factor for that pollutant from the production of aluminum from virgin materials (pounds/ton aluminum)

Ef_{P_B} = emission factor for that pollutant from bauxite grinding (pounds/ton aluminum)

$Ef_{P_{A_1}}$ = emission factor for that pollutant from alumina production (pounds/ton alumina)

$Ef_{P_{A_2}}$ = emission factor that pollutant from aluminum production (pounds/ton aluminum)

and where:

$$Ef_{P_{A_2}} = (Ef_{P_{A_{PBC}}} \times P_{PBC}) + (Ef_{P_{A_{HSC}}} \times P_{HSC}) + (Ef_{P_{A_{VSC}}} \times P_{VSC}) + Ef_{P_{MH}} \qquad \text{(XIII-1a)}$$

where $Ef_{P_{A_{PBC}}}$ = emission factor for that pollutant from aluminum production in prebaked cells (pounds/ton aluminum)

P_{PBC} = proportion of aluminum produced in prebaked cells in 1970 = 61.9% (Reference 33)

$Ef_{P_{A_{HSC}}}$ = emission factor for that pollutant from aluminum production in horizontal-stud Soderberg cells (pounds/ton aluminum)

P_{HSC} = proportion of aluminum produced in horizontal-stud Soderberg cells in 1970 = 25.5% (Reference 33)

$Ef_{P_{A_{VSC}}}$ = emission factor for that pollutant from aluminum production in vertical-stud Soderberg cells (pounds/ton aluminum)

P_{VSC} = proportion of aluminum produced in vertical-stud Soderberg cells in 1970 = 12.6% (Reference 33)

$Ef_{P_{MH}}$ = emission factor for that pollutant from materials handling

*Assumes that one ton of primary aluminum is derived from two tons of alumina that are produced from 4.5 tons of bauxite.

Example: Calculate the aggregate emission factor for total particulates from the production of aluminum from virgin materials

$$\Sigma Ef_p = (4.5 \times 6) + (2 \times 200) + (84.3 \times 0.619) +$$

$$+ (98.4 \times 0.255) + (78.4 \times 0.126) + 10$$

= 524 pounds particulates/ton primary aluminum

2. Calculation of the Emission Factors for Production of Aluminum from Scrap Recovered from Municipal Solid Waste

$$Ef_P = \left[(Ef_{P_{SF}} \times P_{SF}) + (Ef_{P_{RF}} \times P_{RF})\right] \times f \qquad \text{(XIII-2)}$$

where Ef_P = emission factor for that pollutant from aluminum production from scrap metal by secondary aluminum operations (pounds/ton aluminum produced)

$Ef_{P_{SF}}$ = emission factor for that pollutant from sweating furnaces (pounds/ton scrap processed)

P_{SF} = proportion of scrap aluminum processed in sweating furnaces
= 50%

$Ef_{P_{RF}}$ = emission factor for that pollutant from reverberatory furnances (pounds/ton scrap processed)

P_{RF} = proportion of scrap aluminum processed in reverberatory furnaces
= 50%

f = conversion factor (from pounds/ton scrap processed to pounds/ton aluminum produced)
= 1.25

Example: Calculate the emission factor for particulates from secondary aluminum operations

$$Ef_P = \left[(14.5 \times 0.5) + (4.3 \times 0.5)\right] \times 1.25$$
$$= 11.75$$
= ~12 pounds particulates/ton secondary aluminum

3. Calculation of the Quantities of Pollutants That Will Be Emitted in 1990 during Production of 180,000 Tons of Aluminum from Virgin Materials

$$Q_{P_V} = Ef_P \times M_A \times f \qquad \text{(XIII-3)}$$

where Q_{P_V} = quantity of a pollutant from aluminum production from virgin materials (tons)

Ef_P = the aggregate emission factor for that pollutant from aluminum production from virgin materials (pounds/ton aluminum)

M_A = mass of aluminum (tons)

f = conversion factor (from pounds to tons)
= 1/2000

Example: Calculate the quantity of total particulates that would be emitted in 1990 during production of 180,000 tons of aluminum from virgin materials

$$Q_{P_V} = \frac{12 \times 180{,}000}{2000}$$
$$= 1080 \text{ tons particulates}$$

4. Calculation of Quantities of Pollutants That Will Be Emitted in 1990 during Production of 180,000 Tons of Aluminum from the 225,000 Tons of Scrap Aluminum That Will Be Recovered from Municipal Solid Waste

$$Q_{P_R} = Ef_P \times M_A \times f \qquad \text{(XIII-4)}$$

where Q_{P_R} = quantity of a pollutant from aluminum production from recycled material (tons)

Ef_p = emission factor for that pollutant from aluminum production from scrap metal (pounds/ton secondary aluminum)

See Equation XIII-3 for other definitions.

Example: Calculate the quantity of particulates that would be emitted in 1990 during production of 180,000 tons of secondary aluminum from scrap

$$Q_{P_R} = \frac{2.9 \times 180{,}000}{2000}$$
$$= 261 \text{ tons particulates}$$

5. Calculation of Effect of Substituting Scrap Aluminum Recovered from Municipal Solid Waste for Virgin Materials in the Production of 180,000 Tons of Aluminum in 1990

$$\Delta Q_P = Q_{P_R} - Q_{P_V} \qquad \text{(XIII-5)}$$

where ΔQ_P = difference in quantity of a pollutant that would be emitted if scrap aluminum from municipal solid waste is substituted for virgin materials in aluminum production in 1990 (tons)

Q_{P_R} = quantity of the pollutant that would be emitted during aluminum production from recovered material (tons)

Q_{P_V} = quantity of the pollutant that would be emitted during aluminum production from virgin materials (tons)

Example: Calculate the difference in particulate emissions that would result from substituting the scrap aluminum recovered from municipal solid waste for virgin materials in aluminum production

$$\Delta Q_P = 261 - 1080$$
$$= -819 \text{ tons particulates}$$

XIV. POLLUTANTS ASSOCIATED WITH GLASS MANUFACTURE

1. Calculation of the Particulate Emissions Permissible from Glass Manufacture (Reference 37)

$$E = 3.59 \times P^{0.62} \qquad \text{(XIV-1)}$$

where E = maximum permissible particulate emissions (pounds/hour)
P = process weight (tons/hour) if less than 30 tons/hour (Reference 37)

Example: Calculate the maximum quantity of particulates that may be emitted from Furnace #3 of the Glass Containers Corporation manufacturing plant in Dayville, Connecticut

In Example: P = 10 tons/hour (Reference 36)

$$E = 3.59 \times (10)^{0.62}$$
$$= 15.0 \text{ pounds particulates/hour}$$

2. Calculation of Particulate Emission Factors for Glass Manufacture from Virgin Materials and from Cullet Recovered from Municipal Solid Waste*

$$Q_P = \left[(Ef_{V_0} \times P_V) + (Ef_{C_0} \times P_C)\right] \times P \qquad \text{(XIV-2a)}$$

where Q_P = quantity of particulates emitted (pounds/hour)
Ef_{V_0} = emission factor for particulates during glass manufacture from virgin materials (pounds/ton process weight)
P_V = proportion of virgin material in process feed
Ef_{C_0} = emission factor for particulates during glass manufacture from cullet (pounds/ton process weight)

*Based on data for Glass Containers Corporation plant in Dayville, CN (References 36 and 39).

P_C = proportion of cullet in process feed
P = process weight (tons/hour)

Condition 1 - With 80 percent virgin materials and 20 percent cullet, particulate emissions were 152 percent of permissible emissions (Equation XIV-2b)

Condition 2 - With 50 percent virgin materials and 50 percent cullet, permissible level of emissions was not exceeded (Equation XIV-2c)

$$Q_P = \left[(Ef_{V_O} \times 0.8) + (Ef_{C_O} \times 0.2)\right] \times 10 = 1.52 \times E \quad \text{(XIV-2b)}$$

$$Q_P = \left[(Ef_{V_O} \times 0.5) + (Ef_{C_O} \times 0.5)\right] \times 10 = 1.0 \times E \quad \text{(XIV-2c)}$$

where E = maximum permissible particulate emissions (pounds/hour)
= 15.0 pounds/hour (Equation XIV-1 and Example)

From Equations XIV-2b and XIV-2c:

Ef_{V_O} = 2.8 pound particulates/ton virgin materials

Ef_{C_O} = 0.2 pound particulates/ton cullet

For calculation of emission factor in terms of pounds/ton glass:

$$Ef = Ef_O \div EP \quad \text{(XIV-2d)}$$

where Ef = emission factor for particulates (pounds/ton glass)
Ef_O = emission factor (pounds/ton process weight)
EP = production efficiency

For glass manufacture from virgin material:

$$Ef_V = 2.8 \div 0.85$$
$$= 3.3 \text{ pounds particulates/ton glass}$$

For glass manufacture from cullet:

$$Ef_C = 0.2 \div 1$$
$$= 0.2 \text{ pound particulates/ton glass}$$

3. Calculation of Quantities of Pollutants That Will Be Emitted in 1990 during Manufacture of 2,100,000 Tons of Glass from Virgin Materials

$$Q_{P_V} = Ef_V \times M_G \times f \qquad \text{(XIV-3)}$$

where Q_{P_V} = quantity of a pollutant from glass manufacture from virgin materials (tons)
Ef_V = emission factor for the pollutant (pounds/ton glass)
M_G = mass of glass (tons)
f = conversion factor (from pounds to tons)
= 1/2000

Example: Calculate the quantity of particulates that will be emitted in 1990 during the manufacture of 2,100,000 tons of glass from virgin materials

$$Q_{P_V} = \frac{3.3 \times 2{,}100{,}000}{2000}$$

$$= 3465 \text{ tons particulates}$$

4. Calculation of Quantities of Pollutants That Will Be Emitted in 1990 during Manufacture of 2,100,000 Tons of Glass from Cullet Recovered from Municipal Solid Waste

$$Q_{P_C} = Ef_C \times M_G \times f \qquad \text{(XIV-4)}$$

where Q_{P_C} = quantity of a pollutant emitted during glass manufacture from cullet (tons)
Ef_C = emission factor for the pollutant (pounds/ton glass)
M_G = mass of glass (tons)
f = conversion factor (from pounds to tons)
= 1/2000

Example: Calculate the quantity of particulates that will be emitted in 1990 during manufacture of glass from cullet

$$Q_{P_C} = \frac{0.2 \times 2{,}100{,}000}{2000}$$

= 210 tons particulates

5. Calculation of the Effect of Substituting 2,100,000 Tons of Cullet Recovered from Municipal Solid Waste for Virgin Materials in Glass Manufacture in 1990

$$\Delta Q_P = Q_{P_C} - Q_{P_V} \qquad \text{(XIV-5)}$$

where ΔQ_P = difference in the quantity of a pollutant that would be emitted if cullet from municipal solid waste is substituted for virgin materials in glass manufacture in 1990 (tons)

Qp_C = quantity of the pollutant that would be emitted during glass manufacture from cullet (tons)

Qp_V = quantity of the pollutant that would be emitted during glass manufacture from virgin materials (tons)

Example: Calculate the difference in particulate emissions that would result from substitution of 2,100,000 tons of cullet for virgin materials in glass manufacture

$$\Delta Q_P = 210 - 3465$$
$$= -3255 \text{ tons particulates}$$

XV. EFFECT OF IMPLEMENTATION OF MATERIALS RECOVERY FROM MUNICIPAL SOLID WASTE ON POLLUTANTS FROM PRODUCTION OF STEEL, ALUMINUM, AND GLASS IN 1990

1. Calculation of the Total Differences in Quantities of Pollutants Emitted/Discharged That Will Result from Substitution of Materials Recovered from Municipal Solid Waste for Virgin Materials in Production of Steel, Aluminum, and Glass in 1990

$$\Sigma\Delta Q_P = \Delta Q_{P_S} + \Delta Q_{P_A} + \Delta Q_{P_G} \qquad \text{(XV-1)}$$

where $\Sigma\Delta Q_P$ = total difference in quantity of a pollutant emitted/discharged (tons)

ΔQ_{P_S} = difference in quantity of the pollutant that would be emitted/discharged if scrap ferrous metals were substituted for virgin materials in steel production (tons)

ΔQ_{P_A} = difference in quantity of the pollutant emitted/discharged that would result from use of scrap in aluminum production (tons)

ΔQ_{P_G} = difference in quantity of the pollutant emitted/discharged that would result from use of cullet to manufacture glass (tons)

Example: Calculate the total difference in the quantity of particulates that would be emitted during production of steel, aluminum, and glass from recovered materials (from municipal solid waste) rather than from virgin materials

$$\Sigma\Delta Q_P = (-6580) + (-819) + (-3255)$$
$$= -10{,}654 \text{ tons particulates}$$

XVI. ESTIMATED ENERGY CONSERVATION IN MATERIALS PRODUCTION RESULTING FROM REPLACEMENT OF VIRGIN MATERIALS WITH MATERIALS RECOVERED FROM MUNICIPAL SOLID WASTES

1. Calculation of Energy Requirement for Production from Virgin Materials

$$E_V = ER_V \times M \qquad \text{(XVI-1)}$$

where E_V = energy requirement for a given production from virgin materials (million Btu)
ER_V = energy requirement for unit production from virgin materials (million Btu/ton product)
M = mass of product (tons)

Example: Calculate the energy requirement for producing from virgin materials the amount of steel that could be produced from scrap ferrous metals recoverable from MSW in 1990

$$\begin{aligned} E_{V_S} &= ER_{V_S} \times M_S \\ &= 23.3 \times 2{,}565{,}000 \\ &= 59{,}764{,}500 \text{ million Btu} \end{aligned}$$

2. Calculation of Energy Requirement for Production from Materials Recovered from Municipal Solid Waste

$$E_R = ER_R \times M \qquad \text{(XVI-2)}$$

where E_R = energy requirement for a given production from recovered materials (million Btu)
ER_R = energy requirement for unit production from recovered materials (million Btu/ton product)
M = mass of product (tons)

Example: Calculate the energy requirement for producing aluminum from the scrap aluminum recoverable from municipal solid waste in 1990

$$E_{R_A} = ER_{R_A} \times M_A$$
$$= (6 \text{ to } 25) \times 180{,}000$$
$$= 1{,}080{,}000 \text{ to } 4{,}500{,}000 \text{ million Btu}$$

3. Calculation of Energy Requirements for Glass Production

$$E_G = (ER_V \times P_V) + (ER_C \times P_C) \qquad \text{(XVI-3)}$$

where E_G = energy requirement for production of glass (million Btu/ton glass)
= 16.2 with 15 percent cullet (Reference 27)
ER_V = energy requirement for production of glass from virgin materials (million Btu/ton glass)
P_V = proportion of virgin materials in process weight
ER_C = energy requirement for production of glass from cullet (million Btu/ton glass)
P_C = proportion of cullet in process weight

From Reference 27:

$$E_{G_1} = (ER_V \times 0.85) + (ER_C \times 0.15) = 16.2 \qquad \text{(XVI-3a)}$$

From Reference 39:

$$E_{G_2} = (ER_V \times 0.8) + (ER_C \times 0.2) \qquad \text{(XVI-3b)}$$

$$E_{G_3} = (ER_V \times 0.5) + (ER_C \times 0.5) = E_{G_2} \times (0.85 \text{ to } 0.90) \qquad \text{(XVI-3c)}$$

For $E_{G_3} = E_{G_2} \times 0.90$ in Equation XVI-3c, $ER_V = 17.0$ and $ER_C = 11.7$ million Btu/ton glass. For $E_{G_3} = E_{G_2} \times 0.85$ in Equation XVI-3c, $ER_V = 17.4$ and $ER_C = 9.4$ million Btu/ton glass. Average values of 17.2 million Btu/ton glass for ER_V and 10.55 million Btu/ton glass for ER_C are therefore used.

4. Calculation of Energy Requirement for Recovering Materials from Municipal Solid Waste (MSW) in 1990

$$ER = ER_{RR} \times M_{RR} \times P \qquad \text{(XVI-4)}$$

where ER = energy requirement for recovering the material from MSW (million Btu)
ER_{RR} = energy requirement for resource recovery (million Btu/ton of MSW)
= 0.2 million Btu/ton MSW (References 40 and 41)
M_{RR} = mass of MSW that will be processed for resource recovery in 1990 (tons)
= 30,000,000 tons (Table II)
P = proportion of the material in the MSW (Table III)

Example: Calculate the energy requirement for recovering scrap aluminum from MSW in 1990

$$ER = 0.2 \times 30{,}000{,}000 \times 0.01$$
$$= 60{,}000 \text{ million Btu}$$

5. Calculation of Net Difference, That Is, of Energy Conservation Resulting from Materials Production from Recovered Rather than from Virgin Materials

$$\Delta E = E_V - (E_R + ER) \qquad \text{(XVI-5)}$$

where ΔE = the net difference in energy requirement (million Btu)
E_V = energy requirement for production of that material from virgin materials (million Btu)(Equation XVI-1)
E_R = energy requirement for production of that material from recoved materials (million Btu) (Equation XVI-2)
ER = energy requirement for recovery of that scrap from municipal solid waste (million Btu) (Equation XVI-4)

Example: Calculate the energy savings that will be realized in 1990 if cullet recovered from municipal solid waste replaces virgin materials in the manufacture of glass

$$\Delta E_G = 36,120,000 - (22,155,000 + 600,000)$$
$$= 13,365,000 \text{ million Btu}$$

5. Calculation of the Total Energy Savings That Would be Realized in 1990 If Materials Recovered from Municipal Solid Waste Were Substituted for Virgin Materials in the Production of Steel, Aluminum, and Glass

$$\Sigma \Delta E = \Delta E_S + \Delta E_A + \Delta E_G \qquad \text{(XVI-5a)}$$

where $\Sigma \Delta E$ = total energy savings (million Btu)
ΔE_S = net difference in energy requirement for steel production (million Btu)
ΔE_A = net difference in energy requirement for aluminum production (million Btu)
ΔE_G = net difference in energy requirement for glass production (million Btu)

For $\Sigma \Delta E$ in BCOE (barrels of crude oil equivalent), the conversion factor is 5.6 million Btu/barrel of crude oil.

XVII. POLLUTANTS ASSOCIATED WITH ENERGY PRODUCTION

1. Calculation of Emission Factors for Coal Combustion

$$Ef_1 = Ef_2 \times HHV_C \times CE_C \qquad \text{(XVII-1)}$$

where Ef_1 = emission factor for a pollutant (pounds/ton coal)
Ef_2 = emission factor for that pollutant (pounds/million Btu output)
HHV_C = heating value of coal (million Btu/ton)
= 20 million Btu/ton coal
CE_C = combustion efficiency of coal
= 1.0

Example 1: Calculate the maximum particulate emission factor permissible during coal combustion in power plants

$$Ef_1 = 0.1 \times 20 \times 1$$
= 2 pounds particulates/ton coal

Example 2: Calculate the emission factor for carbon monoxide during coal combustion

$$Ef_2 = 1 \div 20 \div 1$$
= 0.05 pound particulates/million Btu output

2. Calculation of Emission Factors for Cofiring of Coal and Refuse-Derived Fuel (RDF)

$$Ef_1 = Ef_2 \times f \qquad \text{(XVII-2)}$$

where Ef_1 = emission factor for a pollutant (pounds/million Btu)
Ef_2 = emission factor for that pollutant (grams/megajoule)
f = conversion factor (from grams/megajoule to pounds/million Btu)
= 2.32

Example: Calculate the emission factor for NO_x during 1977 cofiring of coal-RDF at 80:20 in Ames, Iowa boiler #5 operating at 80% load

$$Ef_1 = 0.067 \times 2.32$$
= 0.16 pound NO_x/million Btu

3. Calculation of Emission Factors for Pollutants from Mass Burning of Municipal Solid Waste (MSW) in Harrisburg, PA Incinerator

$$Ef_1 = Ef_2 \times HHV_{MSW} \times CE_{MSW} \qquad \text{(XVII-3)}$$

where Ef_1 = emission factor for a pollutant (pounds/ton MSW)
Ef_2 = emission factor for that pollutant (pounds/million Btu output)
HHV_{MSW} = heating value of raw refuse
= 8.6 million Btu/ton MSW
CE_{MSW} = combustion efficiency of MSW
= 0.60

Example: Calculate the emission factor for particulates from mass burning of municipal solid waste

$$Ef_2 = \frac{1.02}{8.6 \times 0.6}$$

= 0.20 pound particulates/million Btu output

XVIII. PROJECTED QUANTITIES OF POLLUTANTS FROM ENERGY PRODUCTION IN 1990

1. Calculation of Amounts of Energy That Will Be Produced from Different Substances in 1990

$$EP = M \times HHV \times CE \qquad \text{(XVIII-1)}$$

where EP = energy that will be produced from a substance in 1990 (Btu)
M = mass of the substance (tons)
HHV = average heating value of the substance (Btu/ton)
CE = combustion efficiency of the substance

Subscripts used in examples in Equations XVIII-2 and XVIII-3:

C = coal
MSW = municipal solid waste (energy recovered by mass burning of raw refuse in waterwall incinerators)
MB = mass burning of MSW
RDF = refuse-derived fuel (energy recovered by cofiring with coal at 20:80 ratio based on heat input to boiler)
CF = cofiring of RDF and coal at 20:80

2. Calculation of the Amount of Energy That Will Be Produced from Coal in 1990 without Energy Recovery from Municipal Solid Waste

$$EP_C = M_C \times HHV_C \times CE_C \qquad \text{(XVIII-2)}$$

See Equation XVIII-1 for definitions.

In Example: M_C = 1036 million tons of coal (Reference 44)
HHV_C = 20 million Btu/ton coal
CE_C = 1.0

$$EP_C = 1036 \times 10^6 \times 20 \times 10^6 \times 1.0$$
$$= 20720 \times 10^{12} \text{ Btu}$$

3. Calculation of the Amounts of Energy That Will Be Produced in 1990 from Coal and from Municipal Solid Waste through Energy Recovery

Example 1: Calculate the amount of energy that will be recovered from RDF in 1990

$$EP_{RDF} = M_{RDF} \times HHV_{RDF} \times CE_{RDF} \qquad \text{(XVIII-3a)}$$

See Equation XVIII-1 for definitions.

In Example: M_{RDF} = 11,250,000 tons (Table XI)
HHV_{RDF} = 11 million Btu/ton RDF
CE_{RDF} = 0.65

$$EP_{RDF} = 11{,}250{,}000 \times 11 \times 10^6 \times 0.65$$
$$= 80.4 \times 10^{12} \text{ Btu}$$

Example 2: Calculate the amount of energy that will be produced in cofiring of RDF and coal at 20:80 in 1990

$$EP_{CF} = EP_{RDF} + EP_C \qquad \text{(XVIII-3b)}$$

$$= EP_{RDF} + (4)(M_{RDF} \times HHV_{RDF})(CE_C)$$

See Equation XVIII-1 for definitions.

In Example: EP_{RDF} = 80.4×10^{12} Btu (Equation XVIII-3a)
CE_C = 1.0

$$EP_{CF} = (80.4 \times 10^{12}) + (4)(11{,}250{,}000)(11 \times 10^6)(1.0)$$
$$= (80.4 \times 10^{12}) + (495 \times 10^{12})$$
$$= 575.4 \times 10^{12} \text{ Btu}$$

Example 3: Calculate the amount of energy that will be recovered in 1990 from MSW by mass burning in waterwall incinerators

$$EP_{MB} = M_{MSW} \times HHV_{MSW} \times CE_{MSW} \qquad \text{(XVIII-3c)}$$

See Equation XVIII-1 for definitions.

In Example: M_{MSW} = 15 million tons (Table XI)
HHV_{MSW} = 9 million Btu/ton MSW
CE_{MSW} = 0.60

$$EP_{MB} = 15 \times 10^6 \times 9 \times 10^6 \times 0.60$$

$$= 81 \times 10^{12} \text{ Btu}$$

Example 4: Calculate the amount of energy that will be produced by coal combustion in 1990 if there is energy recovery from municipal solid waste

$$\Sigma EP = EP_C - EP_{CF} - EP_{MB} \qquad \text{(XVIII-3d)}$$

See Equation XVIII-1 for definitions.

In Example: $\Sigma EP = 20720 \times 10^{12}$ Btu (Equation XVIII-2)
$EP_{CF} = 575.4 \times 10^{12}$ Btu (Equation XVIII-3b)
$EP_{MB} = 81 \times 10^{12}$ Btu (Equation XVIII-3c)

$$EP_C = 20720 - 575.4 - 81$$
$$= 20063.6 \times 10^{12} \text{ Btu}$$

Example 5: Calculate the amount of coal that will be combusted in coal-fired power plants in 1990 with implementation of resource recovery from MSW

$$M_C = EP_C \div HHV_C \div CE_C \qquad \text{(XVIII-3e)}$$

See Equation XVIII-1 for definitions.

In Example: $EP_C = 20064 \times 10^{12}$ Btu (Equation XVIII-3d)

$$M_C = \frac{20063.6 \times 10^{12}}{20 \times 10^6 \times 1.0}$$

$$= 1003 \text{ million tons of coal}$$

Example 6: Calculate the proportion of energy that will be produced from each fuel/by each method in 1990 with resource recovery

$$\Sigma EP = EP_C + EP_{CF} + EP_{MB} \qquad \text{(XVIII-3f)}$$

See Equation XVIII-1 for definitions.

In Example: $\Sigma EP = 20720 \times 10^{12}$ Btu (Equation XVIII-2)
$EP_C = 20063.6 \times 10^{12}$ Btu (Equation XVIII-3d)
$EP_{CF} = 575.4 \times 10^{12}$ Btu (Equation XVIII-3b)
$EP_{MB} = 81 \times 10^{12}$ Btu (Equation XVIII-3c)

Example 6a: Calculate the proportion of energy that will be produced by coal combustion in coal-fired power plants

$$P_C = EP_C \div \Sigma EP$$
$$= 20063.6 \div 20720$$
$$= 96.8 \text{ percent}$$

Example 6b: Calculate the proportion of energy that will be produced by cofiring of RDF and coal at 20:80

$$P_{CF} = EP_{CF} \div \Sigma EP$$
$$= 575.4 \div 20720$$
$$= 2.8 \text{ percent}$$

Example 6c: Calculate proportion of energy that will be produced by mass burning of MSW

$$P_{MB} = EP_{MB} \div \Sigma EP$$
$$= 81 \div 20720$$
$$= 0.4 \text{ percent}$$

4. Calculation of Quantities of Pollutants That Will Be Emitted during Energy Production in 1990

$$Q_P = Ef_P \times EP \times f \qquad \text{(XVIII-4)}$$

where Q_P = quantity of a pollutant emitted during energy production by a given method (tons)

Ef_P = emission factor for that pollutant during energy production by that method (pounds/million Btu output) (data from Table XVII)

EP = energy production by that method (Btu) (Equations XVIII-2 and XVIII-3)

f = conversion factor (from pounds to tons) = 1/2000

Example: Calculate the quantity of particulates that will be emitted from coal-fired power plants in 1990 without energy recovery

$$Q_P = \frac{0.1 \times 20720 \times 10^{12}}{2000 \times 10^6}$$

$$= 1{,}036{,}000 \text{ tons particulates}$$

5. Calculation of Total Quantities of Pollutants Emitted in 1990 during Energy Production Which Includes Energy Recovery from Municipal Solid Waste

$$\Sigma Q_P = Q_{P_C} + Q_{P_{CF}} + Q_{P_{MB}} \qquad \text{(XVIII-5)}$$

where ΣQ_P = total quantity of a pollutant (tons)
Q_{P_C} = quantity of the pollutant emitted during coal combustion (tons)
$Q_{P_{CF}}$ = quantity of the pollutant emitted during cofiring of RDF and coal at 20:80 (tons)
$Q_{P_{MB}}$ = quantity of the pollutant emitted during mass burning of municipal solid waste in waterwall incinerators (tons)

Example: Calculate the total quantity of particulates that will be emitted in 1990 during energy production under the scenario that includes resource recovery

$$\Sigma Q_P = 1{,}003{,}180 + 28{,}770 + 8100$$
$$= 1{,}040{,}050 \text{ tons particulates}$$

XIX. EFFECT OF ENERGY RECOVERY FROM MUNICIPAL SOLID WASTE (MSW) ON THE QUANTITIES OF POLLUTANTS THAT WILL BE EMITTED IN 1990 DURING ENERGY PRODUCTION

1. Calculation of the Effect of Energy Recovery on Pollutant Quantities

$$\Delta Q_p = \Sigma Q_p - Q_p \qquad \text{(XIX-1)}$$

where ΔQ_p = difference in quantity of a pollutant emitted as the result of energy recovery from MSW (tons)

ΣQ_p = total quantity of the pollutant emitted during energy recovery from MSW (tons) (Table XVIII)

Q_p = quantity of the pollutant emitted during energy production by coal combustion without resource recovery (tons) (Table XVIII)

Example: Calculate the effect of energy recovery from MSW on the quantity of particulates that will be emitted during energy production in 1990

$$\Delta Q_p = 1{,}040{,}050 - 1{,}036{,}000$$
$$= +4050 \text{ tons particulates}$$

XX. LANDFILL CAPACITY REQUIREMENT FOR DISPOSAL OF MUNICIPAL SOLID WASTE (MSW)

1. Calculation of Weight of Refuse/Residue Requiring Landfill Disposal

$$M_L = M \times P_W \qquad \text{(XX-1)}$$

where M_L = weight of refuse/residue that will be landfilled (tons)

M = mass of MSW that is subject to given procedure (tons)

P_W = proportion of original weight remaining after procedure
- = 0.25 after incineration
- = 1.0 after landfilling
- = 0.12 after resource recovery

Example: Calculate the weight of the incinerator residue that will be landfilled in 1990

$M_L = 10 \times 10^6 \times 0.25$

= 2,500,000 tons of incinerator residue

2. Calculation of Volume of Refuse/Residue That Will Be Landfilled in 1990

$$V_L = M_L \div D \times f \qquad \text{(XX-2)}$$

where V_L = volume of material in landfill (cubic yards)

M_L = weight of landfilled material (tons) (Equation XX-1)

D = density of the material in the landfill (pounds/cubic yard)
- = 2700 pounds/cubic yard for incinerator residue
- = 800 pounds/cubic yard for landfilled MSW
- = 2000 pounds/cubic yard for residue from resource recovery

f = conversion factor (from tons to pounds)
- = 2000

Example: Calculate the landfill volume that will be required for disposal of incinerator residue in 1990

$$V_L = \frac{2{,}500{,}000 \times 2000}{2700}$$

= 1,851,852

= ~1.85×10^6 cubic yards

3. Calculation of Required Landfill Capacity

$$LC = V_L \times f \qquad \text{(XX-3)}$$

where LC = required landfill capacity (acre-feet)
V_L = volume of material in the landfill (cubic yards)
f = conversion factor (from cubic yards to acre-feet)
= 0.0006198

Example: Calculate the landfill capacity that will be required in 1990 to dispose of the resource recovery residue from municipal solid waste generated in 1990

$$LC = 3{,}600{,}000 \times 0.0006198$$
$$= 2231$$
$$= \sim 2230 \text{ acre-feet}$$

4. Calculation of Total Required Landfill Capacity for Disposal of Municipal Solid Waste (MSW) Generated in 1990

$$\Sigma LC = LC_I + LC_L + LC_{RR} \qquad \text{(XX-4)}$$

where ΣLC = total required landfill capacity (acre-feet)
LC_I = landfill capacity required to dispose of incinerator residue (acre-feet)
LC_L = landfill capacity required to dispose of landfilled raw refuse (acre-feet)
LC_{RR} = landfill capacity required to dispose of resource recovery residue (acre-feet)

Example 1: Calculate the landfill capacity required for disposal of MSW in 1990 under scenario without resource recovery

$$\Sigma LC = 1150 + 289{,}760 + 0$$
$$= 290{,}910 \text{ acre-feet}$$

Example 2: Calculate the landfill capacity required for disposal of MSW in 1990 under scenario for implementation of resource recovery

$$\Sigma LC_{RR} = 1150 + 243{,}270 + 2230$$
$$= 246{,}650 \text{ acre-feet}$$

5. Calculation of the Effect of Resource Recovery on the Landfill Capacity Required for Disposal of Municipal Solid Waste (MSW) in 1990

$$\Delta\Sigma LC = \Sigma LC_{RR} - \Sigma LC \qquad \text{(XX-5)}$$

where $\Delta\Sigma LC$ = difference in landfill capacity requirement if scenario for resource recovery is implemented (acre-feet)

ΣLC_{RR} = required landfill capacity with resource recovery (acre-feet) (Equation XX-4, Example 2)

ΣLC = required landfill capacity if there is no resource recovery (acre-feet) (Equation XX-4, Example 1)

$$\Delta\Sigma LC = 246{,}650 - 290{,}910$$
$$= -44{,}260 \text{ acre-feet}$$

XXI. SUMMARY OF EFFECTS ON THE ENVIRONMENT OF RESOURCE RECOVERY FROM MUNICIPAL SOLID WASTE

In these calculations:

$\Sigma\Delta Q$ = total change in quantity of a pollutant emitted/discharged (tons)

ΔQ_D = change in quantity of the pollutant emitted/discharged through disposal of the MSW (tons) (Table X)

ΔQ_{MP} = change in quantity of the pollutant emitted/discharged during materials production (tons) (Table XV)

ΔQ_{EP} = change in quantity of the pollutant emitted/discharged during energy production (tons) (Table XIX)

Q_{CF} = quantity of the pollutant emitted/discharged during cofiring of coal and RDF that is attributable to the RDF (Table IX)

1. Calculation of the Net Changes in Quantities of Air Pollutants That Would Be Emitted to the Environment as the Result of Implementation of Resource Recovery from Municipal Solid Waste (MSW) in 1990

$$\Sigma\Delta Q = \Delta Q_D + \Delta Q_{MP} + \Delta Q_{EP} - Q_{CF} \qquad \text{(XXI-1)}$$

Example: Calculate the change in the quantity of particulates emitted from MSW in 1990 with resource recovery from the MSW

$\Sigma\Delta Q$ = (+14,850) + (-10,654) + (+4050) - (+7200)
= +1046 tons particulates

APPENDIX B

ESTIMATION OF LEACHATE QUALITY BY EQUILIBRIUM MODELING

Equilibrium modeling was used to predict the quality of leachate from the landfilled residue of municipal solid waste that remains after resource recovery. The equilibrium approach to modeling was selected because concentrations of complexes can be expressed as a function of the free metal and free ligand concentrations using mass law equations.

The equilibrium modeling was based on the following assumptions pertaining to the residue from resource recovery (i.e., the solid phase):

- Elemental analyses of incinerator residue are valid.
- Metals are present in the most stable oxidation state for an oxygen-saturated aqueous environment. Therefore, unless there is specific compound identification, metals are in the form of hydroxides (except for the oxides of aluminum, silicon, and titanium) and silicates.
- Nonmetals are present in the most stable oxidation state for an oxygen-saturated aqueous environment. Phosphorus and sulfur are therefore present as phosphate and sulfate respectively.
- Trace elements that are identified in leachate are present in the landfilled residue in hydroxide form at concentrations of less than 0.10 mole percent.
- The organic matter in combustion residue is inert.

- Organic species which act as strong complexing agents are not present in significant quantities.
- Microbial action within the landfill is minimal because of lack of suitable organic substrates.
- Biological degradation of inorganic species is negligible.

On the basis of these assumptions and available data, a hypothetical composition of the solid phase was formulated (Table B-I).

The equilibrium modeling was based on the following assumptions pertaining to the leachate (i.e., the liquid phase):

- Formulation of a generic leachate based on available data is valid.
- The principal factors affecting metal solubility are pH, pE, and complexing ability. Of these, pH is the most important.
- Leaching in a landfill occurs only when the landfill is saturated.
- Absorption equilibria are unimportant.

On the basis of these assumptions and available data, a hypothetical composition of the liquid phase was formulated (Table B-II).

The assumptions made for the other variables that define the landfill environment are listed in Table B-III.

On the basis of these assumptions, the equilibrium concentrations of the various elements in leachate from landfilled resource recovery residue were calculated by equilibrium modeling according to Chemical Equilibrium Program #REDEQL2 that was developed by the Keck Laboratory of Environmental Engineering Science at the California Institute of Technology in Pasadena, California (References 50 and 51).

TABLE B-I

HYPOTHETICAL COMPOSITION OF THE SOLID PHASE[a]

CONSTITUENT	CONTENT	
	Mole %	Weight %
$CaSO_4$	3.27	3.47
$CaSiO_3$	9.80	8.90
$Ca(OH)_2$	8.71	5.03
$Ca_3(PO_4)_2$	2.18	5.27
$Mg(OH)_2$	8.71	3.97
$MgSiO_3$	16.34	12.81
Al_2O_3	5.45	4.34
$Pb(OH)_2$[b]	0.05	0.10
SiO_2	18.52	8.68
$Cd(OH)_2$[b]	0.10	0.11
$Zn(OH)_2$	0.54	0.43
$Cu(OH)_2$	2.18	1.66
$Mn(OH)_2$	1.10	0.76
$MnSiO_3$	1.10	1.11
$Fe(OH)_3$	3.27	2.72
$Sn(OH)_2$	0.08	0.10
$Mg(OH)_2$[b]	0.05	0.10
$Ni(OH)_2$[b]	0.02	0.02
TiO_2	6.54	4.07
$K_2O \cdot Al_2O_3 \cdot 6SiO_2$	4.36	21.57
$Na_2O \cdot Al_2O_3 \cdot 2SiO_2$	7.63	14.77

[a]Based on composition data in Reference 47.

[b]Added constituent.

TABLE B-II

HYPOTHETICAL COMPOSITION OF THE LIQUID PHASE

DESCRIPTION	CONSTITUENTS
Eluant simulates a natural leachate pH 5.00	0.15 M acetic acid 0.15 M sodium acetate distilled water

TABLE B-III

PARAMETERS DEFINING THE LANDFILL ENVIRONMENT

PARAMETER	ASSUMPTION
Temperature	25°C, ambient
Pressure	1 atmosphere, ambient
Liquid-to-solid ratio	2:1
Solid density	2.6 g/cm^3
Bulk density	0.5 g/cm^3